JOHN CURTIS FRANKLIN / ATHENS

Hearing Greek Microtones

Introduction

Microtonal intervals occupy an important place in ancient Greek music theory, beginning with Archytas and Aristoxenus, our earliest witnesses (early and late fourth century BC respectively). It is certain that their treatments reflect an important dimension of practice.[1] Yet most performances today render the ancient Greek fragments with uniformly diatonic intonation. To be sure, many of the late pieces are in fact in the diatonic genus. And even for those which do exhibit the non-diatonic *pykná* – the 'close set' pitches at the bottom of a tetrachord – the notation system does not distinguish between enharmonic and chromatic, much less specify which 'shade' (*khróa*) is to be used. Furthermore, these microtonal shadings surely rank among the more culturally peculiar, and therefore elusive to the modern performer, elements of Greek practice. Nevertheless, Archytas, Eratosthenes (third century BC), Didymus (first century AD) and Ptolemy (second century AD) propose exact ratios for the intervals of non-diatonic systems, and even versions of the diatonic with microtonal modifications. It would be unfortunate if, in the current renaissance of performing Greek music, re-enactors continued to overlook this important material, which could bring greater life both to the fragments and to new music based on ancient principles.

That the practical and theoretical position of microtones in ancient Greek music may be understood as concretely as possible, this lecture includes, in addition to the essential philological arguments, a number of audio demonstrations. It is therefore both about performance, and a sort of performance itself.

---

[1] Winnington-Ingram 1932; Burkert 1972, 388; Barker 1989, 46–52.

First I explain and demonstrate the basic acoustic phenomena which bear on the Greek use of microtonal intervals – namely the harmonic series, harmonic 'refraction', and resonance between musical tones. It is to be hoped that most researchers of ancient Greek music are already familiar with the physical laws involved. Yet probably even some of these scholars – alongside perhaps the majority of those philologists who have recently recognized the importance of music for the anthropology of ancient Greece, but are still daunted by the technical material of the ancient theorists – have never heard these phenomena demonstrated. And yet they are basic to the entire history of Greek tonality, which, though a 'technical' subject in the first instance, is often crucial for a proper understanding of the social and political dimensions of ancient Greek music.

I then discuss two distinct customs in the Greeks' use of resonance. The perfect fifth and fourth, the most audible resonances after the octave, characterized the diatonic, chromatic and enharmonic genera in their classical, textbook form. By the late fifth century, however, the lesser resonances were frequently used in some genres (especially citharody and the dithyramb) to give microtonal 'shadings' to all three genera, and this practice continued to grow for several centuries thereafter. Many of the tunings preserved by the theorists, and expressed as ratios between successive degrees, are commonly supposed to owe as much to mathematical fantasy as musical reality. An analysis of their internal relations, however, reveals how their scalar presentation conceals an extensive basis in lesser resonant relations. Since such intervals are easily audible even to us, one may be all the more certain that, if the ancient authors took the trouble to record them, they reflect ancient musical practice quite faithfully. Some true mathematical fictions remain, but these exceptions mark the rule. Finally, there is a distinct tendency for these lesser resonances to be arranged in reference to the central string *mésē*, which was of great practical importance for the 'classical', i.e. Archaic, seven-stringed *kithára*, both in tuning and performance. I conclude therefore with an étude employing *mésē* in accord with allusions in ancient sources, thereby highlighting these intervals and the character they impart to the *harmonía*.

The Harmonic Series

A musical tone results from regular, periodic oscillation, for example a vibrating string (as with the *kithára*) or a column of air (in the *aulós*). Generally a tone, though apparently a single pitch, is actually a complex of

pitches, a spectrum which includes both the perceived pitch and a series of overtones occuring at integer multiples of a fundamental frequency.[2] Typically the perceived pitch is also the fundamental (although with the tones of a tuba, for instance, the fundamental can be subaudible), and often the overtones which are present form the complete harmonic series – that is, 1:2:3:4:5:6:7:8:9:10:11:12, and so on, where '1' represents the fundamental frequency and the succeeding numbers its integer multiples. Each overtone, considered in isolation, is a sine-wave, the simplest form of oscillation, unencumbered by a harmonic series of its own. The timbre of an instrument is determined by the relative and evolving amplitude of its overtones, and in some cases not every overtone of the harmonic series will be present; in the tones of a cylindrically bored instrument, for example, like the clarinet or Greek *aulós*, only odd-numbered multiples of the fundamental occur.

In Audio Example 1 the harmonic series is demonstrated using a low-pass filter, with which one may attenuate all frequencies above a variable cutoff point. By setting the cutoff frequency to the fundamental and then slowly opening the filter, one can hear each overtone as it is let through, and how the tone's timbre becomes richer with each addition. The best result is given from a low fundamental, with a slight amplification of the cutoff frequency to emphasize the overtones.

Harmonic refraction

The harmonic series has been put to a variety of musical uses in many cultures through what one might call 'harmonic refraction', since these techniques involve breaking apart the harmonic series in order to isolate specific overtones. A ready and familiar example is the jaw-harp, the metal tongue of which provides a fundamental drone from which a melody of partial-tones is extracted by varying the size, and hence resonant cavity, of the mouth. A different application is the controlled overblowing of natural horns to attain various higher partial-tones, a technique highly elaborated in modern valved brass instruments. Finally, the 'harmonics' of violin, guitar, and other stringed instruments are attained by lightly pressing, but not stopping, a string at some whole-number fraction of its overall sounding-length; when the string is plucked or bowed, the corresponding overtone will sound.

---

[2] See e.g. Helmholtz 1895, 229.

Although there is no clear evidence that the Greeks ever apprehended the harmonic series as such, they certainly made musical use of harmonic refraction. The *sálpinx*, a type of trumpet, required overblowing through a number of partials. The *aulós* too will have been overblown to its second overtone, a twelfth above the fundamental, and in some cases to the fourth at two octaves and a third.[3]

It also seems certain that the Greeks knew how to produce ovetones on the *kithára* (Audio Example 2).[4] It has been argued that the technique is occasionally depicted on vases from the Archaic and Classical periods, although this evidence leaves some room for doubt.[5] More promising, and generally accepted, is a technique called *syrigmós*, "whistling" (< *sýrinx*, "panpipe"), attributed by Philochorus to Lysander of Sicyon, a citharist of perhaps the early fifth century.[6] The term would be appropriate since an isolated partial is a pure sine-wave, while many whistles and pipes create periodic tones of similar purity (compare the modern term 'flageolet tones').

Resonance

Resonance, the partial coincidence of two tones' waveforms, may be viewed as the inversion of harmonic refraction. Since intervals of different magnitudes cannot be equally resonant, resonance is a relative quality. The vast majority of possible intervals are not audibly resonant. The most obviously resonant intervals duplicate one of the whole-number relationships which occur between successive overtones low down in the harmonic series. They 'resound' because the positive and negative extremes of their oscillations are mutually reinforcing; in effect they 'recombine' into a single unrefracted tone, or at least one length of that tone's harmonic series. Whether they occur low or high in the series, such

---

[3] Howard 1893, 30–35; West 1992a, 102f. On the auletic syrinx, see further Hagel 2004 and in this volume.

[4] Cf. Sachs 1924, 293; Winnington-Ingram 1956, 186. In this and the following audio examples, I have used a digital sample of a linen-stringed lyre built by Susanna Rühling, to whom I am very grateful.

[5] Roberts 1980, 47f.; Maas/Snyder 1989, 92f.; Thurn 1998, 414 n. 11.

[6] Eupolis, fr. 110; Philochorus, *FGrH* 328F23 (=Ath. 637f–638a). The term *mágadis* is equally suggestive of octave-overtones: cf. Barker 1982; West 1992a, 69; 341. The technique may also be intended at Quint., *Inst. Or.* 1.12.3: cf. Thurn 1998, 416ff. Lysander's dating is uncertain, but see West 1992a, 69; Barker 1984, 300 n. 205.

ratios take the form $\frac{n+1}{n}$ (like the 3:2 fifth, 4:3 fourth, and 9:8 wholetone), whence they are called epimoric (Greek) or superparticular (Latin). The degree of resonance relates to where the corresponding interval would occur in an overtone series: tones blend less harmoniously the farther the interval occurs from the implied fundamental, because there is less and less coincidence of oscillation. The octave (2:1) is the most resonant and completely blending interval, followed by the intervals 3:2, 4:3, 5:4 and so on.

In Audio Example 3, two oscillators begin at the same pitch. The pitch of one is then slowly raised. As the two diverge from resonant unity or *homophōnía*, one hears a 'beating' effect, the rate of which equals the difference in frequency between the two tones. The oscillator then sweeps up to demonstrate the high degree of resonant blending which characterizes the perfect fifth (3:2). Gradually it decreases in pitch, stopping successively to illustrate the decreasing resonance of the intervals 4:3, 5:4, 6:5, 7:6, 8:7, 9:8, 10:9, 11:10, and 12:11. The intervals from 5:4 to 7:6 are noticeably resonant, with the 5:4 third being especially obvious. From 8:7 onwards, it is increasingly difficult to detect the resonant effect.

Aristoxenus: consonance and diatony

By convention, 'consonant' (Greek *sýmphōnos*) describes only the most audibly resonant intervals. Even here, however, convention varies. In early modern times, for example, the 5:4 third was recognized as consonant, and this usage persists in western music today, although its natural basis has been weakened by equal temperament. In Aristoxenian theory, by contrast, the *symphōníai* were limited to the octave, fifth and fourth (and their various octave compounds). Only with these intervals, according to a definition of Nicomachus which finds parallels in many other sources, do

> the component tones, though different in size, when struck together or at least when ringing together, blend with each other in such a way that the sound produced by them is unitary and like one".[7]

[7] Nicom., *Ench.* 12 (262.1–5): σύμφωνα [*sc.* διαστήματα] μέν, ἐπειδὴ οἱ περιέχοντες φθόγγοι διάφοροι τῷ μεγέθει ὄντες, ἅμα κρουσθέντες ἢ ὁμῶς ποτὲ ἠχήσαντες ἐγκραθῶσιν ἀλλήλοις οὕτως, ὥστε ἑνοειδῆ τὴν ἐξ αὐτῶν φωνὴν γενέσθαι καὶ οἷον μίαν. Other sources collected by Scheltema 1932, 241f.

The octave itself was often called *antíphōnos* in contrast to the "first consonances" (*prôtai symphōníai*) of the fourth and fifth, since 'antiphonal' notes had equivalent tonal functions (*isodynamôn* in Ptolemy), and formed the only interval at which melodic movement might be sung in parallel, as typically by boys and men.[8] Here, then, is a first sign of recognition that degree of resonance was relative. The fifth and fourth were sufficiently less resonant than the octave to n o t be tonally equivalent – and could therefore give rise through extended combination to a series of distinct functions (*dynámeis*) – but were still so closely allied that there could be a strong impression of unity.

Aristoxenus classified all other intervals as 'dissonant' (*diáphōna*). Such relations are described by Cleonides as having a "rough effect on the hearing", and by Sextus Empiricus as "moving the hearing unevenly and intermittently".[9] But behind the strict Aristoxenian dichotomy one may detect his awareness of a less categorical point of view:

> Of the interval sizes, the consonances seem either to be wholly without range of variation [*tópos*], being rather defined by one size, or to have an altogether insignificant range of variation. The non-consonances, by contrast, experience this much less. For these reasons our perception is much more trusting of the consonant interval sizes than the non-consonant, and the tuning of a non-consonant interval would be most precise when it is arrived at through consonance.[10]

Here the *prôtai symphōníai* are recognized as extremely precise – though not infinitely so, that honour presumably reserved for unisons and octaves. Conversely, Aristoxenus does not say that *diáphōna* could not blend *at all*,

---

[8] We find the terms *antíphōnos*, *antōidós*, *homóphōnos*, and *isodynamôn*. Cf. *Aristot. Pr.* 19.7, 13–14, 16–19, 23–24, 34–35, 39, 41–42, 50; Thrasyllus ap. Theo Sm. 48.19f.; 51.15; Ptol., *Harm.* 1.6 (13.4f.), 2.3 (50.20), 2.8 (58.21–24), 2.10 (63.19); Aristid. Quint. 1.8 (14.15–18), 2.14 (80.4); Gaud. 20 (347.26); Porph., *in Harm.* 104.5ff. Cf. Pindar, fr. 125 S-M; Diogenes, *TGF* 776. For the term *antíphōnos* and possible variations of meaning, see Scheltema 1932.

[9] Cleonid. 5 (188.2): τραχυνθῆναι τὴν ἀκοήν; cf. Plut., *De anim. procr.* 1021b for the 9:8 τόνος as τραχύ; Sext. Emp., *Adv. math.* 6.44: διάφωνοι μέν εἰσιν οἱ ἀνωμάλως τὴν ἀκοὴν καὶ διεσασμένως κινοῦντες; Boeth., *De inst. Mus*. 1.8 (195.9): *aspera*.

[10] Aristox., *Harm.* 55: Ἐπεὶ δὲ τῶν διαστηματικῶν μεγεθῶν τὰ μὲν τῶν συμφώνων ἤτοι ὅλως οὐκ ἔχειν δοκεῖ τόπον ἀλλ' ἑνὶ μεγέθει ὁρίσθαι, ἢ παντελῶς ἀκαριαιόν τινα, τὰ δὲ τῶν διαφώνων πολλῷ ἧττον τοῦτο πέπονθε, [καὶ] διὰ ταύτας τὰς αἰτίας πολὺ μᾶλλον τοῖς τῶν συμφώνων μεγέθεσι πιστεύει ἡ αἴσθησις ἢ τοῖς τῶν διαφώνων· ἀκριβεστάτη δ' ἂν εἴη διαφώνου διαστήματος λῆψις ἡ διὰ συμφωνίας.

only that they did so "much less" than the fifth and fourth. At the same time, the *diáphōna* included intervals like the quarter-tone and ditone which are entirely *unresonant*, the blending of which would be better described as "not at all" rather than "much less".

In this passage then Aristoxenus betrays his awareness of a resonant continuum. As we shall see, this idea had already been carefully explored by Archytas, a figure who was well-known to Aristoxenus – as a fellow Tarantine, a friend of his father Spintharos, a musicological predecessor who was influential in the Pythagorean circles where Aristoxenus received his first training, and eventually as a subject for biography.[11] It follows that Aristoxenus' absolute and arbitrary division between the *prôtai symphōníai* and all other intervals – some resonant, others not – was due not to ignorance but a conscious choice motivated by the requirements of his theory. It places in a position of supremacy a tuning tradition for which only the intervals 3:2 and 4:3 were needed.

The method of tuning in question is that of "diatonic music" – *diátonos mousiké*, as it appears in Hibeh Papyrus 13, possibly our earliest witness of the term (*c.*400).[12] In the basic form assumed by Philolaus, Plato, Aristoxenus, many of the Aristotelian *Problems*, Euclid, and Eratosthenes, the successive intervals are *hypátē* 256:243 *parypátē* 9:8 *likhanós* 9:8 *mésē* 9:8 *paramésē* 256:243 *trítē* 9:8 *paranḗtē* 9:8 *nḗtē* (approximately e-f-g-a-b-C-D-E, without implying equal temperament). Such scalar or 'linear' presentation of a tuning is found in all the ancient theorists. This format, while presenting the facts efficiently, obscures the resonant relationships between non-adjacent degrees which were generative of the consecutive intervals in the first place. (It is still more misleading to represent these tunings in cents, since this compounds the disadvantage of linearity with taking equal temperament as a point of reference, which is already a distortion of natural intonation.) In the case of the familiar diatonic, these resonant cross-relationships are ready to our minds. In the microtonal scales which will be considered below, however, the linear presentation becomes much more cryptic. Therefore I shall present all tunings in a matrix display, showing their cross-relationships, and the steps for creating them. (Only the epimoric relations which concern

---

[11] Iambl., *Vit. Pyth.* 197, 251; *Suda* s.v. ᾽Αριστόξενος; Diog. Laer. 1.118. See further Laloy 1904, 1–16.

[12] *PHib.* 13.19, improved text West 1992b. For the early fourth-century dating, Brancacci 1988. In fact I am inclined to agree with Barker 1984, 185 n. 12, who sees Aristoxenian influence in the text; and Wallace 1995, 32ff. and n. 32.

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.949	0.844	**3:4**	**2:3**	0.633	0.563	**1:2**
ph	1.053	1	**8:9**	0.790	0.702	**2:3**	0.593	0.527
l	1.185	**9:8**	1	**8:9**	0.79	**3:4**	**2:3**	0.593
m	**4:3**	1.266	**9:8**	1	**8:9**	0.844	**3:4**	**2:3**
pm	**3:2**	1.424	1.266	**9:8**	1	0.949	0.844	**3:4**
t	1.580	**3:2**	**4:3**	1.185	1.053	1	**8:9**	0.791
pn	1.778	1.688	**3:2**	**4:3**	1.185	**9:8**	1	**8:9**
n	**8:9**	1.899	1.688	**3:2**	**4:3**	1.266	**9:8**	1

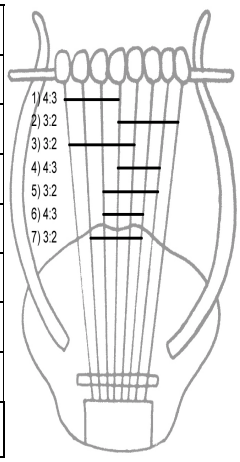


Figure 1: Simple diatonic

us here are given as ratios, in boldface; all others remain in decimal form, a necessary result of my method of calcuation). Thus the simple diatonic appears as follows (Figure 1, with Audio Example 4):

Aristoxenus' championing of the diatonic accounts for the central elements of his theory. First is his emphasis on the strings. The *aulós*, which liberated musici<ans from the heptatonic restrictions of the *kithára*, delivered a powerful new charge to Greek music from the late Archaic period onwards. Consequently it was basic to much of the theory of Aristoxenus' predecessors, including the formulation of the Perfect System (*sýstēma téleion*) itself in the second half of the fifth century (as Stefan Hagel demonstrates in this volume).[13] Aristoxenus himself was an authority on the *aulós*, having written on the instrument, its boring, and its most famous practitioners.[14] Moreover, his innovative system of *tónoi* – forerunners of the later pitch-keys assumed in the fully developed notation system[15] – was intended to account for modulation, a practice which, originally alien to *kithára* music, was developed largely by *aulós* players, particularly in the realm of the dithyramb, whence it spread in time to other

[13] See Hagel 2000, 165ff. and his contribution to this volume. This discovery is surely relevant to the designation of *auloí*, known to Aristoxenus (fr. 101), as *téleioi* ('complete') and *hypertéleioi* ('extra-complete').

[14] Aristox., *frr.* 100–101**;** on the identity of these works, see the comments of Wehrli 1967, ad loc.

[15] Cf. West 1992a, 228–232.

genres.[16] It is therefore all the more significant that, even in the fourth century after *auloí* had acquired sophisticated accessories, and innovators like Pronomus of Thebes had made it possible to play in several tunings (or keys) on a single set of pipes,[17] Aristoxenus attests that auletes still had to use every technique at their disposal to achieve the desired intervals, in spite of which "each thing played by an *aulós* misses the mark due to causes inherent in the playing of the instrument".[18] Similarly, Plato had stated that in *aulós* music consonant relationships were merely approximated through "educated guesswork".[19] For Aristides Quintilianus the *aulós* could achieve the same sound-minded ethical effects of the *kithára* only "through much knowledge and sobre judgement", and even then was not altogether uncompromised by a feminizing influence.[20] This is why Aristoxenus, after stating that the 'wonderous nature' of a properly-

---

[16] Modulation within a single piece is first credited to the aulete Sacadas of Argos in the early sixth century (ps.-Plut., *Mus.* 1134b). Lasus of Hermione is then said to have transformed the existing style of music "through the multiplicity of *aulós* notes" (τῇ τῶν αὐλῶν πολυφωνίᾳ, ps.-Plut., *Mus.* 1141c). Pindar, called a student of Lasus (see West 1992a, 344 n. 68), and others also celebrated the *polýkhordos aulós* and its *pámphōnon mélos*: *I.* 5.27, *O.* 7.12, *P.* 12.19; cf. *Adesp.* 29b (*PMG* 947). For *poikilía* as *polyphōnía*, ps.-Plut., *Mus.* 1137a. For a detailed account of this movement, see Wallace 2003. For citharodes' adherence to a single tuning as part of the Mesopotamian patrimony of diatony, see Franklin 2002a, 698–700.

[17] For Pronomus, Paus. 9.12.5; Ath. 631e: cf. Hagel in this volume.

[18] Aristox., *Harm.* 43: ἕκαστα τῶν αὐλουμένων μεταβάλλει ⟨κατὰ⟩ τὰς αἰτίας ἀφ' ὧν αὐλεῖται; cf. 42: πάντων γὰρ τούτων ὑπαρχόντων οὐδὲν ἧττον τὰ μὲν πλείω διαμαρτάνουσιν οἱ αὐληταὶ τῆς τοῦ ἡρμοσμένου τάξεως … ὥστ' εἶναι φανερόν, ὅτι οὐδὲν διαφέρει λέγειν τὸ καλῶς ἐν τοῖς αὐλοῖς τοῦ κακῶς ("For despite the existence of such [*sc.* compensatory] techniques, nonetheless for the most part auletes badly miss hitting the arrangement of the *mélos hērmosménon* … so that clearly it makes no difference to talk about good versus bad *aulós*-playing"); Aristox. ap. ps.-Plut., *Mus.* 1144e; Pratin., fr. 1.8–12 (*PMG* 708) (=Ath. 617b); *Anth. Pal.* (Honestus) 9.216.5.

[19] Plato, *Phlb.* 56a: μουσικὴ … τὸ σύμφωνον ἁρμόττουσα οὐ μέτρῳ ἀλλὰ μελέτης στοχασμῷ, καὶ σύμπασα αὐτῆς αὐλητική, τὸ μέτρον ἑκάστης χορδῆς τῷ στοχάζεσθαι φερομένης θηρεύουσα, ὥστε πολὺ μεμειγμένον ἔχειν τὸ μὴ σαφές, σμικρὸν δὲ τὸ βέβαιον ("Music . . . tuning the consonant not by measurement but by the guesswork of practice, and the whole art of *aulós*-playing [*sc.* is full] of this, hunting after, by guessing, the measure of each note sounded, so as to produce a mixture of much which is unclear, and little which is stable").

[20] Aristid. Quint. 2.19 (91.13f.) διὰ πολλὴν ἐπιστήμην καὶ σωφροσύνην.

formulated heptatonic scale (*mélos hērmosménon*)[21] transcends merely material considerations, insisted that, if such structures must be explained by reference to an earthly instrument, the *aulós* should be avoided at all costs.[22] Thus he criticized those for whom the goal of *harmonikḗ* was "to be able to say in what way, and from where, arise each of the pieces played on the *auloí*",[23] and those who based their formulation of the *tónoi* on the establishment of common ground between various *aulós* scales.[24]

Aristoxenus was the first to admit that chordophones, like any type of instrument, animate or inanimate, were marred by imperfections of their own; the tuning of a *kithára*, once set, will slip with time.[25] But a theorist must be practical: as stated in the Hippocratic *De victu*, "first there needs to be an instrument of music on which you will demonstrate what is

---

[21] Cf. Aristox., *Harm* 5: οὔσης δὲ θαυμαστῆς τῆς τάξεως περὶ τὴν τοῦ μέλους σύστασιν ("though the arrangement concerning the composition of the *mélos* is wonderous" etc.); *Harm.* 42 τάξιν … τῆς φύσεως τοῦ ἡρμοσμένου θαυμαστήν ("the amazing arrangement of the nature of the [*sc. mélos*] *hērmosménon*").

[22] Aristox., *Harm.* 43 σχεδὸν δὴ φανερόν, ὅτι δι' οὐδεμίαν αἰτίαν εἰς τοὺς αὐλοὺς ἀνακτέον τὸ μέλος, οὔτε γὰρ βεβαιώσει τὴν τοῦ ἡρμοσμένου τάξιν τὸ εἰρημένον ὄργανον οὔτ', εἰ τις ᾠήθη δεῖν εἰς ὄργανόν τι ποιεῖσθαι τὴν ἀναγωγήν, εἰς τοὺς αὐλοὺς ἦν ποιητέον, ἐπειδὴ μάλιστα πλανᾶται καὶ κατὰ τὴν αὐλοποιΐαν καὶ κατὰ τὴν χειρουργίαν καὶ κατὰ τὴν ἰδίαν φύσιν ("Indeed, it is quite clear that for no reason is a tuning to be referred to *auloí*, for the instrument named cannot make stable the disposition of the [*sc. mélos*] *hērmosménon*, and, if one thinks the reference must be made to some instrument, it must not be to the *auloí*, since it wanders most [*sc.* in pitch] due to *aulós*-construction, playing technique and its own peculiar nature"). Compare βεβαιώσει with Plato's τὸ βέβαιον (see n. 19 above). There is also an interesting resonance between πλανᾶται and the mosaic in the house of Aion in Paphos, showing the contest of Apollo and Marsyas, above whose head *plánē* is written.

[23] Aristox., *Harm.* 39: τὸ ἔχειν εἰπεῖν τίνα τρόπον ἕκαστα τῶν αὐλουμένων καὶ πόθεν γίγνεται.

[24] Aristox., *Harm.* 37. See further Hagel 2000, 165ff. For the auletic nature of these scales, see n. 52 below.

[25] Aristox., *Harm.* 42–43: εἴ τις οἴεται, ὅτι … ὁρᾷ … τὰς χορδὰς ἐντεταμένας τὰς αὐτάς, διὰ τοῦθ' εὑρήσειν τὸ ἡρμοσμένον ἐν αὐτοῖς διαμένον τε καὶ τὴν αὐτὴν τάξιν διασῶζον, παντελῶς εὐήθης ("If someone thinks that, because . . . he sees . . . the same strings before and after tuning, therefore he will find the [*sc. mélos*] *hērmosménon* persisting in them and preserving the same arrangement, he is altogether naive"); cf. Boeth., *De inst. mus.* 1.10 (196.18–197.3).

wished".[26] Though not explicit in the *Elementa Harmonica*, Aristoxenus exalted strings over winds in his (now fragmentary) work on instruments, and its basic importance is evident from technical terms on every page of his treatise.[27] This preference must also reflect the exalted status which the *kithára* had enjoyed in the Archaic period, when cultivated at the aristocratic symposia, and which continued to condition the growing ambivalence, and even hostility, among the Athenian élite towards the *aulós* and the popular innovations of auletes during the Classical period.[28] And yet the *kithára*'s position of privilege in later theory, especially in a writer like Aristoxenus who professed to reflect musical practice and intended his system to accommodate compositions for both *kithára* and *aulós*, must owe at least as much to musical causes. This is to be explained in the first instance by the intimate connection between the Archaic seven-stringed *kithára* and the diatonic tuning tradition.[29]

Aristoxenus' law of 'continuity' (*synékheia*), his 'first principle' (*arkhḗ*) of *harmonikḗ*, ensured that a scale in any one of the three genera would have a proper heptatonic, and *a fortiori* diatonic, structure.[30] This principle is already to be found in the generic measurements of Archytas (see below), and indeed may be inferred behind the seven *sýmphōnoi khordaí* of the *Homeric Hymn to Hermes*.[31] Original to Aristoxenus, however, was his semitonal distribution of the *tónoi*, which depended on the axiom that a diatonic *tónos* (= 9:8) may be divided into two equal parts. Archytas had already demonstrated mathematically that epimoric intervals

---

[26] Hippoc., *De victu* 1.18: μουσικῆς ὄργανον ὑπάρξαι δεῖ πρῶτον ἐν ᾧ δηλώσει ἃ βούλεται.

[27] Aristox., fr. 95 (=Ath. 174e): ὁ μέντοι Ἀριστόξενος προκρίνει τὰ ἐντατὰ καὶ καθαπτὰ τῶν ὀργάνων τῶν ἐμπνευστῶν, ῥᾴω εἶναι φάσκων τὰ ἐμπνευστά· πολλοὺς γὰρ μὴ διδαχθέντας αὐλεῖν τε καὶ συρίζειν, ὥσπερ τοὺς ποιμένας ("Aristoxenus judges stringed instruments superior to winds, saying that winds are easy; for many people, such as shepherds, play the *aulós* and *sýrinx* with no formal training"); cf. Cic., *Mur.* 13.29. Martianus Capella (2.212) associates Aristoxenus specifically with the lyre, while the mention of Orpheus brings the issue of heptatony to the fore: *conspiceres Orpheum atque Aristoxenum fidibus personantes.*

[28] For the ambivalent position of the *aulós* in Athens, see Wilson 1999, although he does not draw the necessary distincion between the first and second 'waves' of the auletic 'revolution', for which see Wallace 2003.

[29] See Franklin 2002a; 2002b.

[30] See Franklin 2002b, 446f.

[31] Cf. Franklin 2003.

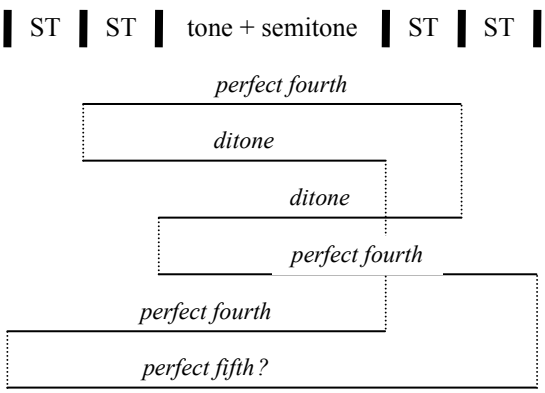


Figure 2: Aristoxenus' experiment

could not in fact be equally divided, and the problem was clearly familiar to Philolaus as well.[32] Aristoxenus was certainly aware of this fact, but the sacrifice of mathematical precision brought him great practical advantages – so great that he really did not need to defend his position with a 'proof' which has since become notorious (cf. Figure 2):

> Whether it was correctly supposed in the beginning that a fourth is two and a half tones, one might test most precisely as follows:
>
> 1. Take a fourth [*parypátē–paran□tē*], and
> 2. Establish through consonance a ditone in relation to each extreme [*parypátē–trítē, likhanós–paran□tē*] …
> 3. After this, take a fourth up from the lower boundary tone of the upper ditone [*likhanós–n□tē*], and
> 4. A fourth down from the upper boundary tone of the lower ditone [*hypátē–trítē*] …
> 5. When things have been thus prepared, we must submit to the judgement of perception the extremities of the tones we have established [*hypátē–n□tē*]. Now if they appear to be non-consonant, it is clear that a fourth will not be two and a half tones, but if they are consonant at a fifth, it is clear that a fourth will be two and a half tones.[33]

---

[32] Ptol., *Harm.* 1.13 (30.9); Boeth., *De inst. mus.* 3.11 (47A19 D-K). For Philolaus, see West 1992a, 235f.

[33] Aristox., *Harm.* 56–57: πότερον δ' ὀρθῶς ὑπόκειται τὸ διὰ τεσσάρων ἐν ἀρχῇ δύο τόνων καὶ ἡμίσεος, κατὰ τόνδε τὸν τρόπον ἐξετάσειεν ἄν τις ἀκριβέστατα· εἰλήφθω γὰρ τὸ διὰ τεσσάρων καὶ πρὸς ἑκατέρῳ τῶν ὅρων ἀφορίσθω δίτονον διὰ συμφωνίας … μετὰ δὲ τοῦτο τῷ τὸ ὀξύτερον δίτονον ἐπὶ τὸ βαρὺ ὁρίζοντι διὰ τεσσάρων εἰλήφθω ἐπὶ

The whole process is reproduced in Audio Example 5, in which each interval is precisely tuned by intervals of 3:2 and/or 4:3 in the order prescribed. The "extremities of the tones" are then submitted "to the judgement of perception", by being compared (twice) with a true resonant fifth, from which they differ by 24 cents – i.e., very audibly. This exposé is not really fair, since it pits the merciless precision of a computer against the ear's judgement of ten successive *symphōníai*, which would of course lead to a slightly different result every time; indeed, Aristoxenus may have been perfectly satisfied with his experiment given his position that the *symphōníai* could tolerate a slight *tópos* of variation[34] – although more likely this admission was intended to blur the problem. The whole procedure would be ideally suited to an experimental instrument of 12 strings.[35] This doubtless reflects the structure of Aristoxenus' *diágramma polýtropon*.

And so it would be pedantic and misplaced to fault Aristoxenus, as many ancient authors did, for his equal semitones. At any rate, the conception did not originate with him, but was deeply rooted in the ancient and widespread practice of diatonic music, being encountered already in the Old Babylonian 'Retuning Text' (*c*.1800 BC).[36] It is not surprising then that even among Aristoxenus' predecessors, who were chiefly concerned with developments in *aulós* music, one finds precedents for the promotion of diatony as a theoretical foundation. The degrees of the Perfect System, which reflected the typical range of the mature late Classical *aulós* and was at heart a practical structure,[37] were nevertheless named, by its unknown inventor, through an abstraction of the string names of the Archaic *kithára*. And among the early theorists who formulated systems of *tónoi* to account for modulatory auletic structures, one predicted Aristoxenus in his use of

---

τὸ ὀξύ, τῷ δὲ τὸ βαρύτερον δίτονον ἐπὶ τὸ ὀξὺ ὁρίζοντι εἰλήφθω ἕτερον διὰ τεσσάρων ἐπὶ τὸ βαρύ … τούτων δ' οὕτω προκατεσκευασμένων τοὺς ἄκρους τῶν ὁρισμένων φθόγγων ἐπὶ τὴν αἴσθησιν ἐπανακτέον· εἰ μὲν οὖν φανήσονται διάφωνοι, δῆλον ὅτι οὐκ ἔσται τὸ διὰ τεσσάρων δύο τόνων καὶ ἡμίσεος, εἰ δὲ συμφωνήσουσι διὰ πέντε, δῆλον ὅτι δύο τόνων καὶ ἡμίσεος ἔσται τὸ διὰ τεσσάρων.

[34] See Winnington-Ingram 1932, 198f.

[35] See Hagel 2000, 16–20.

[36] For the Retuning Text, see Gurney 1968; Wulstan 1968; Gurney 1994. For the basis of Greek diatony in Near Eastern tradition, with further literature on the Retuning Text, see Franklin 2002a, 669 and n. 1; 2002b as a whole, with sources in 442 n. 5.

[37] See Hagel in this volume.

tones and semitones – although this approach was not carried to its logical conclusion.[38]

That step was taken by Aristoxenus who, in his *diágramma polýtropon*,[39] repeated the Perfect System thirteen times in steps of a semitone across a single octave – the essential interval of heptatonic tuning – with an extended diatonic articulation. In doing so, Aristoxenus re-grounded *harmonikḗ* in a traditional method, subsuming the "multiplicity of *aulós* notes" in a comprehensive structure which eclipsed the abortive, aulocentric attempts of his predecessors. By extending the diatonic structures which were the ancient prerogative of the seven-stringed *kithára*, he harmonized earlier lyric and auletic approaches in a single system which addressed the needs of both instruments, as well as their concerted performance in complex modern compositions requiring frequent modulation (like the *Paean* of Athenaeus would be [*DAGM* 20]). The tunings of the *kithára* were restored to theoretical equality, if not their ancient superiority. Diatony, with its resonant fifths and fourths, thereby persisted as the ultimate foundation of music, so that it remained true, as Plutarch later stated, that "on the whole the business of *harmonikḗ* is concerned with the *symphōníai*".[40]

Microtonality

And yet, despite Aristoxenus' insistence that *harmonikḗ* be underpinned by the *prôtai symphōníai* and diatonic structure, it is clear that the use of lesser resonant intervals was widespread. This may be deduced both from other authorities and from Aristoxenus himself, who relegates them to a subordinate status among certain shades (*khróai*) of the chromatic and diatonic genera; here they are further obscured by their presentation as tone-fractions rather than ratios, in keeping with his diatonic thesis of the equally-dividable tone.

This is the practice to which the 'microtones' of my title alludes. 'Microtonal' is a modern construction, and implies the twelve theoretically uniform'semitones of our equal tempered system, from which the microtones may deviate. With a slight change of nuance, however, the term

---

[38] Aristox., *Harm.* 37.

[39] For the reconstruction of Aristoxenus' *diágramma polýtropon*, see Hagel 2000, 183–188.

[40] Plut., *De E Delph.* 389d: τὸ γὰρ πλεῖστον … ἔργον ἁρμονικῆς περὶ τὰς συμφωνίας ἐστίν.

will be appropriate for describing ancient Greek practice. Here too we encounter the idea of deviation from a norm, a norm based on the idea of the 'tone'. In its most basic sense, Greek *tónos* denoted a single, stable pitch.[41] But it is its secondary meaning which is relevant here, *tónos* as the interval "by which a fifth exceeds a fourth",[42] regarded as the most "intellgible" interval, being to music what the cubit was to the measurement of physical space.[43]A series of such *tónoi* (and eventually 'semitones') are created by the alternation of fifths (3:2) and fourths (4:3), known to Aristoxenus as "taking through consonance" (*hē lêpsis dià symphōnías*), and it is this which, according to many ancient authorities, gave diatonic music its name.[44] Such structures, as we shall see, operated as the 'unshaded' point of reference for the various 'shaded' intonations recorded by the ancient theorists. The process is also the point of departure for equal temperament – which, from an ancient Greek perspective, could itself be regarded as a form of microtonality.

A term which does have a basis in ancient usage is 'chromaticism'. There is, however, a confusion in some of the sources, which seems to reflect historical developments in the use of microtones. Aristoxenus used *khrôma* to denote the chromatic genus, the tetrachords of which, in its textbook form (the *toniaîon khrôma*), are divided as semitone + semitone + tone and a half. Like the diatonic, then, the *toniaîon khrôma* must be tuned through *hē lêpsis dià symphōnías*, and this conception is also found in the chromatic of Archytas, who insisted on 9:8 tones in the face of mathematical complications (see below). But a second metaphor of color or aspect is found in the 'shades' (*khróai*) which Aristoxenus permitted in the chromatic and diatonic genera, and frowned on in the enharmonic (see below). At some point the distinction between the two terms became blurred – if indeed there had not always been some overlap of usage[45] –

---

41 For the various derived meanings of τόνος, cf. Franklin 2002a, 673–75.

42 Aristox., *Harm.* 46: τόνος δ' ἐστὶν ᾧ τὸ διὰ πέντε τοῦ διὰ τεσσάρων μεῖζον.

43 Aristox., *Rhythm.* 2.21; Adrastus ap. Theo Sm. 53.3ff.; 66.19–67.3.

44 Adrastus ap. Theo Sm. 54.12–15; Nicom., *Ench.* 12 (262.14ff.); [Aristid. Quint.] 2.19 (92.22f.); Mart. Cap. 9.956; Boeth., *Inst. mus.* 1.21 (213.7); Anon. Bell. 2.26 (7.14–16).

45 The two ideas appear side by side in Philochorus, *FGrH* 328 F 23 (= Ath. 637f–638a), who attributes the techniques of χρώματά τε εὔχροα to Lysander of Sicyon. Hesychius (s.v. *khrôma*) suggests that the terms could be synonymous (χρῶμα . . . παρὰ τοις μουσικοις χροιά). The same appears from the confused entry in the *Suda* s.v. *khrôma*. See also Rocconi 2004, who collects early uses of the color metaphor.

and a number of later authors give dual definitions of *khrôma* which comprise both *khrôma* and *khróa* as used by Aristoxenus.[46] Already Archytas' chromatic featured resonant shading, while Aristoxenus has shades of the chromatic which did not require the 9:8 tone. Eratosthenes, Didymus and Ptolemy, while still recognizing a distinct chromatic genus, offer *only* shaded versions using either the 10:9 or 8:7 tone (see below and Appendix). Thus the course of musical development seems paralleled by progressive terminological confusion. Although a full treatment of this problem is impossible here, these observations signal the due caution with which I shall use the term 'chromaticism' to mean 'microtonality'.

Archytas: chromaticism and lesser resonance

Winnington-Ingram (1932) demonstrated that many of the Aristoxenian shades can be identified with ratio measurements of Archytas, Eratosthenes, Didymus, and Ptolemy, while some which cannot may be explained as distortions introduced by Aristoxenus' overly systematic development of generic doctrine. That the 'mathematical' theorists could be so aligned with Aristoxenus, the champion of direct experience, made it clear that the former reflected musical practice more closely than previously suspected. Unfortunately the daunting complexity of his arguments have caused even these discoveries to be misunderstood, and there remains a general suspicion that the theorists, when they offer us ratios like 25:24, were largely motivated by a desire for mathematical elegance.

I shall show, however, that such numerical abstruseness is usually only an illusion deriving from the scalar presentation of the tunings: an analysis of cross-relations reveals that nearly every string may be accounted for by the use of the lesser resonances 5:4, 6:5, and 7:6. (A few true mathematical fictions do remain, and these will be considered below.) I hope the demonstrations above have made it clear that these relations are distinctive enough that the Greeks could have employed them musically long before any theorist thought to 'construct them experimentally'. It was not Eratosthenes then who attempted to make his ratios correspond to the fractions of Aristoxenus, but Aristoxenus who tried to present resonant

---

[46] Vitruv 5.4.3; Adrastus ap. Theo Sm. 55.4–7; Nicom., *Ench*. 12 (263.9f.); [Aristid. Quint.] 2.19 (92.19f.); Boeth., *De inst. mus*. 1.21 (213.8–10); Anon. Bell. 2.26 (7.17f.).

intervals as tone-fractions, and thereby obscured matters by the same distortion of natural intonation which underlies his *tónoi*.

There is no doubt of course that Ptolemy's predecessors, at least as far back as Archytas, used experimental means of measuring ratios: but these were to determine the ratios of intervals actually in use, which musicians could tune by ear alone. This is probably what is meant by the report that Archytas tried to "show which consonances were more consonant".[47] Porphyry's wording here makes it seem likely that Archytas attempted to expand the sense of *sýmphōnos* to allow for the continuum of lesser epimoric ratios. Ptolemy, who elsewhere praises Archytas for being the first to assign epimoric values not just to the *prôtai symphōníai* but to smaller intervals, probably had this discussion in front of him when pointing out the illogic of not calling the 5:4 third a *symphōnía*.[48]

It is just this interval which figures in the earliest demonstrable use of lesser resonance. This is found in the context of enharmonic music, where the practice was the subject of heated aesthetic controversy. The enharmonic, with which Aristoxenus and his predecessors were most concerned, derived originally from the *aulós* tradition, which explains its important place in the music of classical drama, where, until the time of Euripides and Agathon, it was used by itself or mixed with the diatonic.[49]

---

[47] Porph., *in Harm.* 107.15ff. (47A17 D-K): …τοὺς συμφώνους μᾶλλον ἐπιδεικνύναι βουλόμενοι…

[48] Ptol., *Harm.* 1.6 (13.23–14.1): ἐμποιεῖ δ' αὐτοῖς οὐ τὴν τυχοῦσαν ἀπορίαν καὶ τὸ μόνοις τούτοις τῶν ἐπιμορίων καὶ πολλαπλασίων προσάπτειν τὰς συμφωνίας, τοῖς δ' ἄλλοις μηκέτι – λέγω δὲ οἷον ἐπιτετάρτοις καὶ τοῖς πενταπλασίοις ἑνὸς εἴδους ὄντος αὐτοῖς πρὸς ἐκείνους ("And it causes them no small difficulty that they assign 'the consonances' only to these epimorics and multiples, and not also to the others – that is, interval ratios like 5:4 and 5:1 – even though when they are compared to the others there is but a single type"); 1.7 (15.8–17) σαφῶς γὰρ διαφέρουσιν ἥ τε διὰ πασῶν καὶ ἡ δὶς διὰ πασῶν τῶν ἄλλων συμφωνιῶν καθάπερ ἐκεῖναι ἐμμελειῶν … σύμφωνοι δὲ οἱ ἐγγυτάτω τῶν ὁμοφώνων … ἐμμελεῖς δὲ οἱ ἐγγυτάτω τῶν συμφώνων … διὸ καὶ συντίθενταί πως οἱ μὲν ὁμόφωνοι τοῖς συμφώνοις, οἱ δὲ σύμφωνοι τοῖς ἐμμελέσι ("For clearly the octave and the double-octave differ from all the other consonances just as they do from the 'melodics' … and consonances are the closest to homophones … and 'melodics' are the closest to consonances … wherefore in a way the homophones go together with the consonances, and the consonances with the 'melodics'").

[49] For Olympus' invention of the enharmonic, Aristox., fr. 83 (=ps.-Plut., *Mus.* 1135a). For the enharmonic and diatonic in tragedy *PHib.* 13.20f.; Psell., *De trag.* 5: ἡ δὲ παλαιὰ τραγικὴ μελοποιΐα γένει μὲν τῷ ἐναρμονίῳ ἐχρήσατο ἀμιγεῖ καὶ μικτῷ γένει

Already in our earliest precise evidence, the irregular enharmonic *aulós* scales reproduced by Aristides Quintilianus from some Classical source (especially the Dorian, Phrygian, Lydian and Mixolydian) exhibit the typically chordophonic separation of the lower and upper halves by 3:2 fifths or 4:3 fourths.[50] This consonant parallelism predicts the full heptatonic *synékheia* of Archytas and Aristoxenus, the latter of whom, by placing the enharmonic at the taxonomic level of *génos*, effectively subordinated it to the 'family traits' of the diatonic. But it is in Aristoxenus' formulation of the enharmonic as quarter tone + quarter tone + ditone + tone + quarter tone + quarter tone + ditone that we see the most striking diatonicization of the enharmonic. That these measurements were no mere products of theoretical convenience, but were exactly intended by Aristoxenus, may be inferred from his statement, quoted above, that the tuning of an interval is "most precise" (*akribestátē*) when arrived at "through consonance" (*dià symphōnías*). For Aristoxenus the pure ditone (81:64), which like the 9:8 *tónos* was a product of the strict alternation of fifths and fourths, was the precisely desired, defining feature of the enharmonic in its classical form, the glory of "the two ancient styles".[51] It

---

τῆς ἁρμονίας καὶ διατόνων, χρώματι δὲ οὐδεὶς φαίνεται κεχρημένος τῶν τραγικῶν ἄχρις Εὐριπίδου; cf. West 1992a, 164, 351; Franklin 2002a, 692.

[50] Aristid. Quint. 1.9. These *harmoníai*, which Aristides claims were those discussed by Plato in the Republic, reappear almost exactly in Pollux, who states that they were auletic tunings (4.78: καὶ ἁρμονία μὲν αὐλητικὴ Δωριστί, Φρυγιστί, Λύδιος καὶ Ἰωνική, καὶ σύντονος Λυδιστί); cf. ps.-Plut., *Mus.* 1136b–1137a, with the comments of Monro 1894, 22. At 1.11 (28.1–7) Aristides discusses the terms ἔκλυσις, σπονδειασμός, and ἐκβολή, rises and falls of 3 or 5 quarter tones which were used "by the ancients for the distinctions of *harmoníai*" (πρὸς τὰς διαφορὰς τῶν ἁρμονιῶν … τοῖς παλαιοῖς), where the *harmoníai* are presumably the 'Damonian' ones he has already given (noting also that Damon's alleged music teachers have connections with the *aulós*: see Wallace 2003, 74 and n. 6). Similarly Bacchius (41–42) associates ἔκλυσις and ἐκβολή specifically with enharmonic music (36–37): cf. Winnington-Ingram 1932, 205.

[51] Aristox., *Harm.* 23: ὅτι δ' ἔστι τις μελοποιΐα διτόνου λιχανοῦ δεομένη καὶ οὐχ ἡ φαυλοτάτη γε ἀλλὰ σχεδὸν ἡ καλλίστη, τοῖς μὲν πολλοῖς τῶν νῦν ἁπτομένων μουσικῆς οὐ πάνυ εὔδηλόν ἐστι, γένοιτο μεντᾶν ἐπαχθεῖσιν αὐτοῖς· τοῖς δὲ συνειθισμένοις τῶν ἀρχαικῶν τρόπων τοῖς τε πρώτοις καὶ τοῖς δευτέροις ἱκανῶς δῆλόν ἐστι τὸ λεγόμενον ("But that there is a certain style of melic composition which needs a ditonic *likhanós*, and that it is not the worst but quite the best style, is entirely unclear to the many who undertake music these days, though it would be if they were inducted. But what I am saying is clear to those who are accustomed to the first and second ancient styles").

is because he wished to uphold and preserve this form that, unlike his diatonic and chromatic genera, he refused to admit any shade in his enharmonic genus.

But this was already a lost cause. In a well-known passage, Aristoxenus lamented that most of his contemporaries were corrupting the pure enharmonic by replacing the ditone (here between *likhanós* and *mésē*) with an interval which was slightly smaller:

> Nearly all musicians today use *likhanoí* which are sharper. And the reason for this is the desire to always be sweet (*glykaínein*). And there is proof that it is this for which they aim: for they spend most of their time in the chromatic, and if at some point they end up in the enharmonic, they lead it near to the chromatic, the *mélos* being drawn along.[52]

Aristoxenus is describing here a preference for the slightly smaller resonant third 5:4 over the strict ditone; moreover, this usage finds remarkable confirmation in the enharmonic ratios given by Archytas (preserved in Ptolemy): *hypátē* 28:27 *parypátē* 36:35 *likhanós* 5:4 *mésē* 9:8 *paramésē* 28:27 *trítē* 36:35 *paranḗtē* 5:4 *nḗtē*.[53] The very audible difference between these two intervals is demonstrated in Audio Example 6, in which first *likhanós–mésē* is played as a ditone, *likhanós* is then sweetened to give 5:4, and finally the two *likhanoí* are played together. The ditone is larger than the 5:4 resonance by 22 cents – almost exactly the amount that is obscured or ignored in Aristoxenus' semitone demonstration discussed above. And yet here the difference is treated as profoundly noticeable and affective to modern audiences – effeminate louts who would vomit bile when they heard true enharmonic music (as Aristoxenus expressed it with his usual charm).[54] There is an inherent tension, then, between the Aristoxenian *tónoi* and the diatonic basis of modulation on the one hand, and on the other a substantial resonant adjustment away from the intonations deriving from *hē lêpsis dià symphōnías*.

Aristoxenus' contrast of the pure ditone with that of the sweetened *likhanós* is rhetorically paralleled by the description of the enharmonic being 'led near' to the chromatic. From this one may establish the equation

---

[52] Aristox., *Harm.* 23: συντονωτέραις γὰρ χρῶνται σχεδὸν οἱ πλεῖστοι τῶν νῦν. τούτου δ' αἴτιον τὸ βούλεσθαι γλυκαίνειν ἀεί. σημεῖον δ' ὅτι τούτου στοχάζουσι, μάλιστα μὲν γὰρ καὶ πλεῖστον χρόνον ἐν τῷ χρώματι διατρίβουσιν, ὅταν δ' ἀφίκωνταί ποτε εἰς τὴν ἁρμονίαν, ἐγγὺς τοῦ χρώματος προσάγουσι συνεπισπωμένου τοῦ μέλους; cf. *Harm.* 46.

[53] This was demonstrated by Winnington-Ingram 1932, 200.

[54] Aristox., fr. 85 (= Plut., *Quaest. conviv*. 711c).

resonant = sweet = chromatic or shaded. Chromaticism as a 'sweetening' of intervals is reflected in several other sources. In the curious passage interpolated in Aristides Quintilianus, the chromatic is called "very sweet/pleasant (*hḗdiston*) and lugubrious".[55] Vitruvius states that the chromatic, "with its subtle delicacy . . . has a sweeter (*suaviorem*) pleasure".[56] Plutarch compares the chromaticism of Agathon, who along with Euripides is said to have introduced this style into tragedy, with the "obsessive sweetness" (*hēdypátheia*) of compulsive floral arrangement.[57]

Now, as mentioned above, early tragic music had been either enharmonic or enharmonic mixed with diatonic. It is unthinkable that Euripides and Agathon did away completely with their musical patrimony and only used the later Aristoxenian chromatic genus. Rather, we must assume that they chromatically 'sweetened' the enharmonic and diatonic material already known to them and their audiences. Thus in the words of Plutarch, Agathon "injected and mixed the chromatic into tragedy", while the Middle Comedy poet Antiphanes praised the dithyrambist Philoxenus for "how well his melodies are blended with modulations and chromaticism".[58] The sweetened enharmonic of Archytas, a slightly younger contemporary of Euripides and Agathon, and a colleague of Plato, provides exact confirmation of this. Thus Aristoxenus, the self-proclaimed champion of direct experience,[59] stubbornly maintained a position which must have been reactionary for nearly a century – although, to be fair, in the formulation of his genera he was doing honour to an important phase of Greek musical history. Nevertheless, his testimony serves to acknowledge the existence of a chromaticized enharmonic, and elsewhere he even stated that such a tuning remained recognizably enharmonic *despite* its sweetening.[60]

---

[55] [Aristid. Quint.] 2.19 (92.19–25): ἥδιστόν τε καί γοερόν.

[56] Vitruv. 5.4.3: *chroma subtili sollertia ac crebritate modulorum suaviorem habet delectationem*.

[57] Plut., *Quaest. Conviv*. 645e: Ἀγάθωνος, ὃν πρῶτον εἰς τραγῳδίαν φασὶν ἐμβαλεῖν καὶ ὑπομῖξαι τὸ χρωματικόν. For Euripides, Psell., *De trag.* 5 (see note 49).

[58] Antiphanes, fr. 207 K-A: τὰ μέλη μεταβολαῖς καὶ χρώμασιν ὡς εὖ κέκραται.

[59] Cf. Barker 1978a; 1978b.

[60] Aristox., *Harm*. 46: τί μᾶλλον τὴν δίτονον λιχανὸν λεκτέον ἢ τὴν μικρῷ συντονωτέραν; ἁρμονία μὲν γὰρ εἶναι τῇ αἰσθήσει κατ' ἀμφοτέρας τὰς διαιρέσεις φαίνεται, τὰ δὲ μεγέθη τῶν διαστημάτων δῆλον ὅτι οὐ ταὐτὰ ἐν ἑκατέρᾳ τῶν διαιρέσεων ("Why should the ditonic *likhanós* be chosen rather than the one which is slightly sharper? For in each disposition it appears as enharmonic to our perception, though it is

There emerges then a picture of pan-generic chromaticism or shading. In fact all of Archytas' tunings make use of lesser resonance, much of which, between non-adjacent strings, is not immediately apparent. Elsewhere in his enharmonic, note that by sweetening *paranḗtē* up to create *paranḗtē–nḗtē* 5:4 – corresponding by *synékheia* to *likhanós–mésē* 5:4 – a 6:5 resonance is created automatically between *mésē* and *paranḗtē* (since 5:4 + 6:5 = 3:2, here *mésē–nḗtē*). This is demonstrated in Audio Example 7, in which *paranḗtē–nḗtē* is first played as a ditone, and then sweetened to 5:4; next *mésē–paranḗtē* is played with *paranḗtē* back in its original position, and then sweetened to give *mésē–paranḗtē* 6:5; finally the trichord *mésē–paranḗtē–nḗtē* is played unsweetened and then sweetened (this yields a minor triad, but there is naturally no suggestion that the Greeks used these three strings in such a way, only the demonstration that they are so tuned).

More striking still is Archytas' unique use of the interval *paramésē–trítē* 28:27 in all three genera; though this seems a 'mathematical fiction' at first glance, it combines with the 9:8 wholetone between *mésē–trítē* to create the non-adjacent resonance 7:6 (the same interval would be found by *synékheia* between *parypátē* and the *hyperypátē*, a tone below *hypátē*, which is mentioned in some sources and may be detected in the scales of Arisitdes Quintilianus, the *Orestes* fragment of Euripides [*DAGM* 3], and the interval of five quarter-tones mentioned as typical of enharmonic music).[61] In this version of the enharmonic then one finds three very audible lesser resonances, two of which are obscured by its scalar presentation (Figure 3).

This figure also illustrates how Archytas' chromaticized enharmonic may be established from pure diatonic tuning in a few simple steps (Audio Example 8):

---

clear that the sizes of the intervals are not the same in each"). Cf. ps.-Plut., *Mus.* 1143ef, drawn from Aristoxenus, which, after stating that earlier *harmonikoí* had not studied diatonic or chromatic music, but only the enharmonic, continues, "for while they disagreed about its shading, nearly everybody agreed about there being only one of this tuning" (περὶ μὲν γὰρ τῆς χρόας διαφέροντο, περὶ δὲ τοῦ μίαν εἶναι μόνην αὐτὴν τὴν ἁρμονίαν σχεδὸν πάντες συνεφώνουν).

[61] See Winnington-Ingram 1932, 205f. I have included the relation between *parypátē* and *hyperypátē* in my diagrams for the sake of completeness, though whenever such a relation occurs, it will always be mirrored in the upper half of the scale. For the terms ἔκλυσις, σπονδειασμός, and ἐκβολή, see n. 52 above.

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.964	0.938	**3:4**	**2:3**	0.643	0.625	**1:2**
ph	1.037	1	0.972	0.778	0.691	**2:3**	0.648	0.519
l	1.066	1.028	1	**4:5**	0.711	0.685	**2:3**	0.533
m	**4:3**	1.286	**5:4**	1	**8:9**	**6:7**	**5:6**	**2:3**
pm	**3:2**	1.446	1.407	**9:8**	1	0.964	0.938	**3:4**
t	1.557	**3:2**	1.459	**7:6**	1.037	1	0.973	0.778
pn	1.599	1.542	**3:2**	**6:5**	1.066	1.028	1	**4:5**
n	**2:1**	1.929	1.876	**3:2**	**4:3**	1.286	**5:4**	1

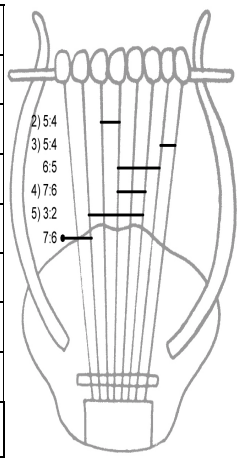


Figure 3: Archytas' enharmonic

1. Tune diatonic (see above).
   1a Tune *parypátē–likhanós* 1:1.
   1b Tune *trítē–paranḗtē* 1:1.
2. Sweeten *likhanós* up to *likhanós–mésē* 5:4.
3. Sweeten *paranḗtē* up to *paranḗtē–nḗtē* 5:4.
4. Sweeten *trítē* down to *mésē–trítē* 7:6.
5. Sweeten *parypátē* by taking *parypátē–trítē* 3:2 (*hyperypátē–parypátē* 7:6 follows).

The assumption of an initial diatonic tuning is justified by several facts. I have already noted that Archytas presents all the genera in heptatonic, and so essentially citharistic, form. Furthermore, the polemic of Aristoxenus against the 5:4 sweetening of the 81:64 ditone makes no sense except in the context of *hē lêpsis dià symphōnías*. Ptolemy provides valuable confirmation when, in presenting a variety of 'chromaticized' *harmoníai*, he states explicitly that the diatonic "is how the citharodes tune".[62] That musicians should first tune thus before making resonant adjustments shows how *synékheia* originated in practice, not theory, since the procedure guarantees a heptatonic foundation despite subsequent shading.

---

[62] Ptol., *Harm.* 2.1 (44.1ff.): οὕτω γὰρ ἁρμόζονται οἱ κιθαρῳδοί; cf. 1.16 (39.17–18) δύο γὰρ ποιοῦσι τοὺς ἡγουμένους τόνους καὶ τὸ λοιπόν, ὡς μὲν αὐτοὶ νομίζουσιν, ἡμιτόνιον ("for they make the leading intervals two tones and the remainder, as they consider it, a semitone").

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.964	**8:9**	**3:4**	**2:3**	0.643	0.593	**1:2**
ph	1.037	1	0.922	0.778	0.691	**2:3**	0.615	0.519
l	**9:8**	1.085	1	0.844	**3:4**	0.723	**2:3**	0.563
m	**4:3**	1.286	1.185	1	**8:9**	**6:7**	0.79*	**2:3**
pm	**3:2**	1.446	**4:3**	**9:8**	1	0.964	**8:9**	**3:4**
t	1.556	**3:2**	1.383	**7:6**	1.037	1	0.922	0.778
pn	1.688	1.627	**3:2**	1.265*	**9:8**	1.085	1	0.844
n	**2:1**	1.929	1.778	**3:2**	**4:3**	1.286	1.19	1

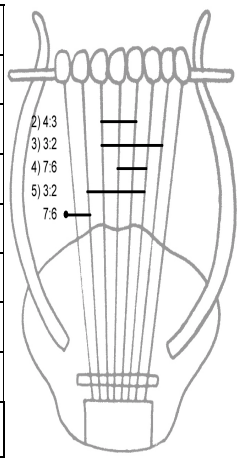


Figure 4: Archytas' chromatic

It is this which explains why a number of pure ditones lurk in tunings which otherwise exhibit the use of lesser resonance. This brings us to Archytas' chromatic (also known to Aristoxenus[63]), which Ptolemy gives as *hypátē* 28:27 *parypátē* 243:224 *likhanós* 32:27 *mésē* 9:8 *paramésē* 28:27 *trítē* 243:224 *paranḗtē* 32:27 *nḗtē*. Once again this will be much clearer from the following (Figure 4, where * indicates the ditone):

1. Tune diatonic.
2. Tune *likhanós–paramésē* 4:3.
3. Tune *likhanós–paranḗtē* 3:2.
4. Sweeten *trítē* down to make *mésē–trítē* 7:6.
3. Sweeten *parypátē* down (according to *synékheia*) to make 3:2 with *trítē* (*hyperypátē–parypátē* 7:6 follows).

This process is reproduced in Audio Example 9. Here we find a ditone between *mésē–paranḗtē* which must have resulted from tuning *likhanós* and *paranḗtē* according to *hē lêpsis dià symphōnías*. Indeed it appears that Archytas left written documentation of this fact, now lost, for Ptolemy states that "in the chromatic genus he takes the second highest note [in the tetrachord, i.e. *likhanós*] from that which has the same position [*likhanós*] in the diatonic". In other words, as he goes on to relate, the interval between *likhanós* in its chromatic and diatonic positions is 256:243, the

[63] Aristox., *Harm.* 52: see Winnington-Ingram 1932, 203.

remainder or *leîmma* created by *hē lêpsis dià symphōnías*.[64] This can only mean that the tuning was first made diatonically, and then *likhanós* was lowered to create 4:3 with *paramésē*; *paranḗtē* was then lowered (according to *synécheia*) to create 3:2 with *paramésē*, and consequently a ditone appeared between *mésē* and *paranḗtē*.

Once again note the non-consecutive resonance 7:6 between *mésē–trítē* (and *parypátē–hyperypátē*). In fact this is the only lesser resonance found in Archytas' chromatic, which is therefore actually *less* 'chromatic' or shaded than his enharmonic. Presumably the ditone was retained to preserve the 9:8 *tónoi* between *paramésē–paranḗtē* and *hypátē–likhanós*, which also characterize the *toniaîon chrôma* of Aristoxenus. A greater degree of chromaticism might have been introduced, on analogy with his enharmonic, by lowering *paranḗtē* slightly to sweeten the ditone *mésē–paranḗtē* to 5:4; the resonance 6:5 would also result between *paranḗtē* and *nḗtē*, as would 10:9 between *paramésē* and *paranḗtē*. In fact this tuning (less the 7:6 *mésē–trítē*) is found as Eratosthenes' chromatic (see Appendix). But this must not be seen as a *mathematical* advance over Archytas, rather a musical variant which used a greater degree of audible 'sweetening'. Conversely we may assume that the intervals of Archytas' chromatic were all equally intentional, because each can be established aurally. It is this, rather than any incompetence, which explains his seemingly abstruse ratio sequence – the significance of which escaped Ptolemy, who considered that Archytas had fallen "hopelessly short" of finding epimorics in the divisions of the tetrachord.[65]

---

[64] Ptol., *Harm.* 1.13 (31.2–4): τὸν δὲ ἐν τῷ χρωματικῷ γένει δεύτερον ἀπὸ τοῦ ὀξυτάτου φθόγγου λαμβάνει διὰ τοῦ τὴν αὐτὴν θέσιν ἔχοντος ἐν τῷ διατονικῷ. Cf. Rocconi 2004. Burkert 1972, 388 goes too far when he says that Archytas derived this "not by reference to the natural concords but by the extrinsic addition of two previously known values, that of the diatonic whole tone (9:8) and the ratio 256:243 – the 'remainder' when two whole tones are subtracted from a fourth": the tuning via *hē lêpsis dià symphōnías* is primary here.

[65] Ptol., *Harm.* 1.13 (30.9ff.) (=47 A 16 D-K): Ἀρχύτας δὲ ὁ Ταραντῖνος μάλιστα τῶν Πυθαγορείων ἐπιμεληθεὶς μουσικῆς πειρᾶται μὲν τὸ κατὰ τὸν λόγον ἀκόλουθον διασῴζειν, οὐκ ἐν ταῖς συμφωνίαις μόνον, ἀλλὰ καὶ ταῖς τῶν τετραχόρδων διαιρέσεσιν, ὡς οἰκείου τῇ φύσει τῶν ἐμμελῶν ὄντος τοῦ συμμέτρου τῶν ὑπεροχῶν. ταύτῃ δ' ὅμως τῇ προθέσει χρησάμενος εἰς ἕνια μὲν καὶ τέλεον αὐτῆς φαίνεται διαμαρτάνων ("Archytas of Tarentum, of all the Pythagoreans the most dedicated to the study of music, tried to preserve what follows the principles of reason not only in the consonances but also in the divisions of the tetrachords, believing that a commensurable relation between the

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.964	0.844	**3:4**	**2:3**	0.643	0.563	**1:2**
ph	1.037	1	**7:8**	0.778	0.691	**2:3**	0.583	0.519
l	1.185	**8:7**	1	**8:9**	0.79*	0.762	**2:3**	0.593
m	**4:3**	1.286	**9:8**	1	**8:9**	**6:7**	**3:4**	**2:3**
pm	**3:2**	1.446	1.265*	**9:8**	1	0.964	0.844	**3:4**
t	1.556	**3:2**	1.313	**7:6**	1.037	1	**7:8**	0.778
pn	1.778	1.741	**3:2**	**4:3**	1.185	**8:7**	1	**8:9**
n	**2:1**	1.929	1.688	**3:2**	**4:3**	1.286	**9:8**	1

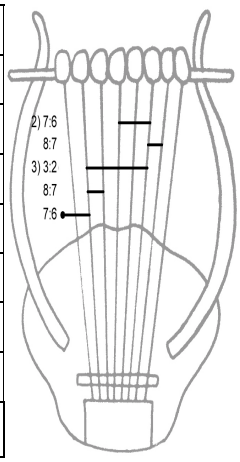


Figure 5: Archytas' diatonic

Ptolemy gives Archytas' diatonic as *hypátē* 28:27 *parypátē* 8:7 *likhanós* 9:8 *mésē* 9:8 *paramésē* 28:27 *trítē* 8:7 *paranḗtē* 9:8 *nḗtē*. This too was known to Aristoxenus, as a form of diatonic with a chromatic *parypátē*.[66] It may be expressed and tuned as follows (Figure 5, Audio Example 10):

1. Tune diatonic.
2. Sweeten *trítē* down to *mésē–trítē* 7:6; *trítē–paranḗtē* 8:7 follows.
3. Sweeten *parypátē* (according to *synécheia*) by taking *parypátē–trítē* 3:2; *parypátē–likhanós* 8:7 follows.

Note that another pure ditone occurs between *likhanós* and *paramésē*. Presumably *paramésē* could not be sweetened because it forms the disjunctive tone, while *likhanós* is necessary for the 8:7 tone with *parypátē*; the 9:8 *likhanós–mésē* was besides a defining feature of the diatonic for Aristoxenus, Eratosthenes, and Didymus alike.

Secondary epimorics and mathematical fictions

In Archytas' diatonic, like his other tunings, *trítē* is sweetened down to make 7:6 *mésē–trítē*. In this case, however, the process creates incidentally, or secondarily, the interval 8:7 (the 'septimal tone') between

---

excesses is a characteristic of the nature of melodic intervals. But though he sets off from this presupposition, at several points he seems to fall hopelessly short of it" [trans. Barker]).

[66] See Winnington-Ingram 1932, 201f.

trítē and *paranḗtē*. This is demonstrated in Audio Example 11, in which first the trichord *mésē–trítē–paranḗtē* is played with an unsweetened *trítē*, which is then retuned to yield *mésē–trítē* 7:6 and *trítē–paranḗtē* 8:7. Because it is a necessary consequence of tuning 7:6 by ear, there is no need to explain it as a mathematical fiction, nor to suppose it could be tuned in isolation. Like the 9:8 tone or the 81:64 ditone of pure enharmonic and diatonic music, the septimal tone could be enjoyed as a secondary creation of an aural tuning process.

This principle lets us explain many of the seeming mathematical fictions in the other theorists (for which see Appendix). The 10:9 tones in the chromatic of Eratosthenes result secondarily from the use of 6:5 thirds. In the genera of Didymus, 6:5 thirds, 10:9 tones, and 16:15 semitones follow from sweetening ditones to 5:4; in his chromatic, this also creates the interval *parypátē–likhanós* 25:24. In Ptolemy's enharmonic and tense diatonic, tuning 5:4 by ear creates 6:5 thirds and 16:15 semitones, while in the soft chromatic, tense diatonic, and even diatonic 10:9 tones also result. In his soft chromatic the use of 5:4, 6:5 and 7:6 thirds generates the secondary intervals 15:14 and 28:27; in the tense chromatic and soft diatonic the 7:6 third causes the appearance of 8:7 tones.

Thus the great majority of the theorists' intervals can be accounted for either through the direct use of the intervals 5:4, 6:5 and 7:6, or as secondary products of them. When this fact is combined with Plato's portrait of *harmonikoí* straining to hear whether an interval is already too small to be further divided,[67] it is hard to avoid the conclusion that the few epimorics which c a n n o t be accounted for in this way are the only true mathematical fictions. Of these, most occur in the division of the *pyknón*, which musicians must often have tuned approximately; yet even here it is important that the intervals which were to be thus bisected (*hypátē–likhanós* and *paramésē–paranḗtē*) are in nearly every case either tunable by audible resonance, or are secondary results of that process elsewhere in the tuning, as detailed above. Thus in Eratosthenes' chromatic 20:19 + 19:18 = 10:9; in Didymus' enharmonic 32:31 + 31:30 = 16:15; in Ptolemy's enharmonic 46:45 + 24:23 = 16:15, tense chromatic 22:21 + 12:11 = 8:7, soft diatonic 21:20 + 10:9 = 7:6, even diatonic 12:11 + 11:10 = 6:5. Eratosthenes and Didymus clearly divided 10:9 and 16:15 arbitrarily by using the two means. (The choices which underly Eratosthenes' enharmonic sequence 40:39 + 39:38 + 19:15, where 19:15 differs from the

[67] Plato, *Rep.* 531ab.

81:64 ditone by only one cent, is a special case which depends upon his divisions of the chromatic.[68]) It is not clear why Ptolemy chose to adopt less equal divisions, but as we shall see there is reason to believe that, despite his criticisms of his predecessors, he reflects ancient practice less accurately than Archytas, Eratosthenes or Didymus; and while it is clear that he intended his analyses to reflect scales actually in use, his detailed descriptions of experimental interval construction[69] lead to the suspicion that measurements like 12:11 in his tense chromatic, 10:9 in his soft diatonic, and 12:11 and 11:10 in his even diatonic (his own invention), are idealized or 'kanonical'.

Chromaticism, *mésē*, and the *kithára*

Whether the use of lesser resonance originated in the *aulós* (consider e.g. the tone-fractions recorded by Aristoxenus as typical of proto-enharmonic music, and the fact that Archytas left a treatise on the *aulós*[70]), the *kithára* (with its precise, stable tones so well suited for the purpose), or whether it was co-evolved by both auletes and citharists, is a problem beyond the scope of this paper. It is clear at least that the tunings known from Archytas come from a time when such intervals, whatever their origin, were commonly employed in music for the *kithára*. A close connection between chordophones and chromaticism has already been seen in the use of an initial diatonic tuning as the basis for the three chromaticized genera of Archytas (and the same case may be made for those of the later theorists: see Appendix). In another publication I have discussed a number of non-Aristoxenian sources which describe the chromatic genus as a variety of the diatonic, and of course the term 'coloring' itself presupposes just such an 'uncolored' point of reference (n.b. these sources exhibit the fusion of Aristoxenian *khrôma* and *khróa* in the single term *khrôma*).[71]

Besides the basic observance of *synékheia*, we have already encountered one consequence of this diatonic substructure: the toleration of pure ditones where one or both bounding notes occupy a pitch, the coloring

---

[68] Winnington-Ingram 1932, 198.

[69] Ptol., *Harm.* 1.16, 2.12–16; cf. West 1992a, 170f., 240–242.

[70] Ath. 184e.

[71] *PHib* 13.13–22; Nicom., *Ench*. 7 (249.4ff.); [Aristid. Quint.] 2.19 (92.19–22); Boeth., *Inst. mus*. 1.21 (213.8–10); Anon. Bell. 2.26 (7.17–18 Najock); Bryenn., *Harm.* 1.7 (114.5f. Jonker). See further Franklin 2002b, 447; Rocconi 2004.

of which would destroy the basic character of the tuning. Such indispensable ditones are also found in Eratosthenes' chromatic (*parypátē–mésē* and *trítē–nḗtē*) and Didymus' diatonic (*paramésē–likhanós*: see Appendix). The most extreme version of this would of course be the classical enharmonic and diatonic represented by Aristoxenus and Eratosthenes. Here one thinks also of Nicomachus' statement that "a certain natural necessity" governs the diatonic progression.[72]

A striking instance of this 'rule of necessity' also demonstrates the adaptation of chromaticism to a specifically citharistic technique. A number of sources allude to the important role of the central string *mésē* in the tuning of the *kithára* and the performance of music in the classical idiom which preceded the auletic revolution of the fifth century, and persisted to some extent despite it.[73] These sources cannot be discussed fully here, and indeed have not yet been adequately studied; nor can we be sure how universally valid such statements were.[74] Taken together they claim that *mésē* was the first string to be tuned, that the others were tuned in relation to it, that it was frequently repeated in all good melodies, and even that this degree was the pitch from which melodies started. The following passage bears most closely on the the present point:

> Why is it that, if *mésē* is changed, the other strings also sound spoiled, whereas if *mésē* remains while one of the other strings is changed, only the changed string is spoiled? Is it because for all the strings being in tune consists of having some relation towards *mésē* – and the pitch of each is already [established] through that string? Thus, when you take away the cause of their being in tune and that which holds them together, it no longer appears to be the same. But if one of the strings is out of tune while *mésē* maintains its pitch, it makes sense for that string alone to be left out of the tuning, since the being-in-tune persists for the others.[75]

---

[72] Nicom., *Ench*. 7 (249.1–3): τὴν δὲ πρόβασιν ἀνάγκῃ τινὶ φυσικῇ … κατὰ τοῦτο τὸ διατονικὸν γένος.

[73] The relevant sources include Aristot., *Metaph*. 1018b26ff.; Aristox., *Harm.* 47; *Aristot. Pr.* 19.20; 25, 19.33, 19.36; 19.44; Plut., *Mor.* 745b, 1008e; Dio Chrys. 68.7; Cleonid. 11 (201.16ff.).

[74] I present a detailed discussion in Franklin 2002c, 265ff. Cf. Winnington-Ingram 1936, 4ff.; cf. West 1992a, 219; Franklin 2002b, 441.

[75] *Aristot. Pr.* 19.36: Διὰ τί, ἐὰν μὲν ἡ μέση κινηθῇ, καὶ αἱ ἄλλαι χορδαὶ ἠχοῦσι φθειρόμεναι, ἐὰν δὲ αὖ ἡ μὲν μένῃ τῶν δ' ἄλλων τις κινηθῇ, ἡ κινηθεῖσα μόνη φθείρεται; – Ἢ ὅτι τὸ ἡρμόσθαι ἐστὶν ἁπάσαις τὸ ἔχειν πως πρὸς τὴν μέσην [ἁπάσαις *secl.* Winnington-Ingram], καὶ ἡ τάξις ἡ ἑκάστης ἤδη δι' ἐκείνην. ἀρθέντος οὖν τοῦ αἰτίου τοῦ ἡρμόσθαι καὶ τοῦ συνέχοντος οὐκέτι ὁμοίως φαίνεται ὑπάρχειν. μιᾶς δὲ ἀναρμόστου

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.937	0.900	**3:4**	**2:3**	0.625	0.600	**1:2**
ph	1.067	1	0.960	**4:5**	0.711	**2:3**	0.640	0.533
l	**10:9**	1.042	1	**5:6**	0.741	0.695	**2:3**	0.556
m	**4:3**	**5:4**	**6:5**	1	**8:9**	**5:6**	**4:5**	**2:3**
pm	**3:2**	1.406	1.350	**9:8**	1	0.937	0.900	**3:4**
t	1.600	**3:2**	1.450	**6:5**	1.067	1	0.960	**4:5**
pn	1.667	1.563	**3:2**	**5:4**	**10:9**	1.042	1	**5:6**
n	**2:1**	1.875	1.799	**3:2**	**4:3**	**5:4**	**6:5**	**1**

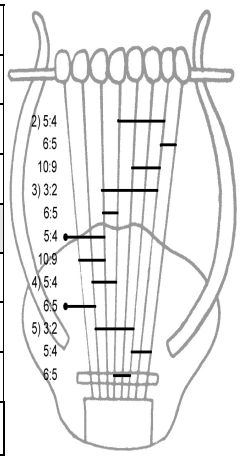


Figure 6: Didymus' chromatic

It is clear that only chordophones are envisioned here. The general terms of the passage let us assume that the principle applied to all three of the genera. But if it is right that the various intervals of a tuning were constructed in relation to *mésē*, it would be all the more important that this string remain stable if chromaticism were at stake, since even the smallest adjustment would spoil a lesser resonance.

There is in fact a distinct tendency for the lesser resonances to be oriented towards the central string, as may be seen from the charts above and in the Appendix, where there is often a concentration of boldfaced ratios in the axes which represent relations with *mésē.* This may be readily observed for all three of Archytas' tunings, Eratosthenes' chromatic, the three genera of Didymus, and to a lesser degree those of Ptolemy. The tunings of Didymus, which involve a greater amount of lesser resonance than even Archytas, are perhaps most striking. Consider for example the intervals of his chromatic genus (*hypátē* 16:15 *parypátē* 25:24 *likhanós* 6:5 *mésē* 9:8 *paramésē* 16:15 *trítē* 25:24 *paranḗtē* 6:5 *nḗtē*), presented in Figure 6 (with Audio Example 12):

1. Tune diatonic.
2. Sweeten down *paranḗtē* to *mésē–paranḗtē* 5:4; *paranḗtē–nḗtē* 6:5, *paramésē–paranḗtē* 10:9 follow.

οὔσης, τῆς δὲ μέσης μενούσης εὐλόγως τὸ κατ' αὐτὴν ἐκλείπει μόνον, ταῖς δὲ ἄλλαις ὑπάρχει τὸ ἡρμόσθαι. Note the resonance of τοῦ συνέχοντος with Aristoxenian συνέχεια.

3. Sweeten down *likhanós* by taking *likhanós–paranḗtē* 3:2; *likhanós–mésē* 6:5, *hyperypátē–likhanós* 5:4, *hypátē–likhanós* 10:9 follow.
4. Sweeten up *parypátē* to *parypátē–mésē* 5:4, *hyperypátē–parypátē* 6:5 and *hypátē–parypátē* 16:15 follow.
5. Sweeten up *trítē* by taking *parypátē–trítē* 3:2; *trítē–nḗtē* 5:4, *mésē–trítē* 6:5 follow.

The exceptions may be readily explained. The enharmonic and diatonic of Eratosthenes reflect the 'ancient style' also upheld by Aristoxenus, in which the strict application of *hē lêpsis dià symphōnías* generates no lesser resonance. This need not, however, negate the general principle of *mésē*-orientation since, for example, the crucial ditone *likhanós-mésē* itself exists in relation to *mésē*. The case of Ptolemy, the latest of the theorists under consideration, is revealing. His enharmonic and soft chromatic show the epicentric structure. His tense chromatic, soft diatonic, and even diatonic – which he invented himself – do not especially. These are also the tunings which display the highest concentration of intervals which c a n n o t be established as secondary epimorics from 5:4, 6:5 and 7:6. These facts, when combined with Ptolemy's failure to grasp the significance of Archytas' ratios and his fondness of experiment, lead to the conclusion that the role of *mésē* in Archaic *kithára* music had been greatly weakened, or altogether eclipsed, by the second century AD (doubtless owing to the rather different perspective of the elaborate pitch-key system of later centuries). The *mésē*-orientation which appears in the enharmonic and soft chromatic may then be explained as fossils due to Ptolemy's development of his predecessors' versions.

Conclusion

I close with a brief étude, emphasizing *mésē* in accord with the ancient evidence, through being the tone with which the piece starts, and through frequent repetition (Audio Example 13). Note that the rhythm is not especially Greek, although the piece might pass as a citharodic prelude (*anabolḗ*) in which the *harmonía* is established. It is repeated six times, using each of the following tunings once: 1) pure diatonic 2) Archytas' diatonic 3) ditonic enharmonic 4) Archytas' enharmonic 5) Archytas' chromatic 6) Didymus' chromatic. The goal is to demonstrate how *mésē*, as the tonal focus, is crucial for bringing out the character of the tuning's

chromaticism, and how this character changes significantly depending on both genus and the various shades recorded by the theorists.

Appendix

These scales are usually studied and discussed in terms of ratios between consecutive degrees, which is how they are presented in the ancient sources. Here they are presented in a matrix to reveal all possible cross-relations between strings. From this it emerges that nearly every relation derives from the use of the audible resonances 5:4, 6:5, and 7:6. The few exceptions – 'mathematical fictions' in the *pyknón* and some of Ptolemy's more experimental tunings – have been discussed in the text. My method of calculation gave results in decimal form rather than as ratios; Only those figures which are significant epimorics have I replaced with ratios, which appear in boldface, while the figures 5:4, 6:5, and 7:6 are also underlined. Tunings which have already appeared as figures in the text are duly noted.

Archytas

Enharmonic: Figure 2 above, with Audio Example 8.

Chromatic: Figure 3 above, with Audio Example 9.

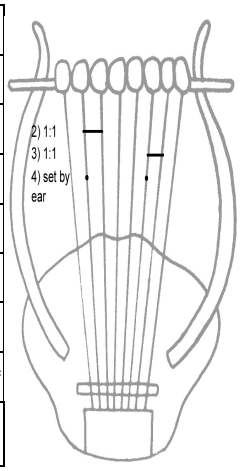
Diatonic: Figure 4 above, with Audio Example 10.

Eratosthenes

Enharmonic: Audio Example 14.

hypátē	40:39	*parypátē*	39:38	*likhanós*	19:15	*mésē*	9:8
paramésē	40:39	*trítē*	39:38	*paranḗtē*	19:15	*nḗtē*	

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.975	0.950	**3:4**	**2:3**	0.650	0.633	**1:2**
ph	1.026	1	0.974	0.769	0.684	**2:3**	0.646	0.513
l	1.053	1.026	1	0.789*	0.702	0.684	**2:3**	0.556
m	**4:3**	1.300	1.266*	1	**8:9**	0.867	0.844	**2:3**
pm	**3:2**	1.462	1.425	**9:8**	1	0.975	0.950	**3:4**
t	1.539	**3:2**	1.461	1.154	1.026	1	0.974	0.769
pn	1.579	1.540	**3:2**	1.184	1.053	1.026	1	0.789*
n	**8:9**	1.950	1.900	**3:2**	**4:3**	1.300	1.266*	1

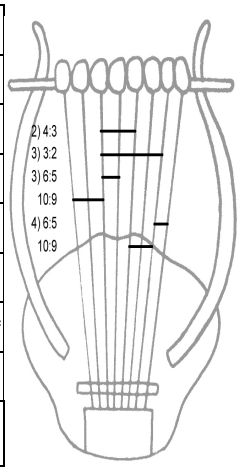


1. Tune diatonic.
2. Tune down *likhanós* to *parypátē-likhanós* 1:1.
3. Tune down *paranḗtē* to *trítē-paranḗtē* 1:1 (or *likhanós-trítē* 3:2).
4. Set *parypátē* and *trítē* by ear (i.e. approximately).

Chromatic: Audio Example 15.

hypátē 20:19 *parhypátē* 19:18 *likhanós* 6:5 *mésē* 9:8
paramésē 20:19 *trítē* 19:18 *paranḗtē* 6:5 *nḗtē*

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.950	**9:10**	**3:4**	**2:3**	0.633	0.600	**1:2**
ph	1.053	1	0.947	0.789*	0.702	**2:3**	0.631	0.526
l	**10:9**	1.056	1	**5:6**	0.741	0.704	**2:3**	0.556
m	**4:3**	1.266*	**6:5**	1	**8:9**	0.844	**4:5**	**2:3**
pm	**3:2**	1.425	1.350	**9:8**	1	0.950	**9:10**	**3:4**
t	1.579	**3:2**	1.421	1.184	1.053	1	0.947	0.789*
pn	1.667	1.584	**3:2**	**5:4**	**10:9**	1.056	1	**5:6**
n	**2:1**	1.900	0.764	**3:2**	**4:3**	1.266*	**6:5**	1



1. Tune diatonic.
2. Tune *likhanós* down to *likhanós-paramésē* 3:4.
3. Tune *paranḗtē* down to *likhanós-paranḗtē* 3:2.

4. Sweeten *likhanós* down to *likhanós-mésē* 6:5; *hypátē-likhanós* 10:9 follows.
5. Sweeten *paranḗtē* down to *paranḗtē-nḗtē* 6:5; *paramésē-paranḗtē* 10:9 follows.

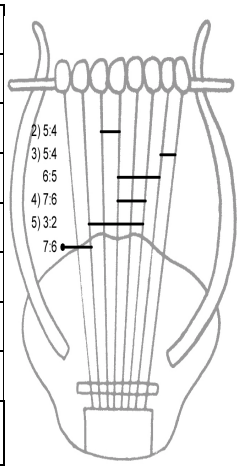
Diatonic: Figure 1 above, with Audio Example 4.

Didymus

Enharmonic: Audio Example 16.

hypátē	32:31	*parypátē*	31:30	*likhanós*	5:4	*mésē*	9:8
paramésē	32:31	*trítē*	31:30	*paranḗtē*	5:4	*nḗtē*	

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.969	0.938	**3:4**	**2:3**	0.646	0.625	**1:2**
ph	1.032	1	0.968	0.774	0.688	**2:3**	0.645	0.516
l	1.066	1.034	1	**5:4**	0.711	0.689	**2:3**	0.533
m	**4:3**	1.292	**5:4**	1	**8:9**	0.861*	**5:6**	**2:3**
pm	**3:2**	1.454	1.407	**9:8**	1	0.969	0.938	**3:4**
t	1.548	**3:2**	1.451	1.161	1.032	1	0.968	0.774
pn	1.599	1.550	**3:2**	**6:5**	1.066	1.034	1	**4:5**
n	**2:1**	1.939	1.876	**3:2**	**4:3**	1.292	**5:4**	1



1. Tune diatonic.
   1a. Tune *parypátē-likhanós* 1:1.
   1b. Tune *trítē-paranḗtē* 1:1
2. Sweeten *likhanós* up to *likhanós-mésē* 5:4; hypátē-*likhanós* 16:15 follows.
3. Sweeten *paranḗtē* up to 5:4; *mésē-paranḗtē* 6:5 follows.
4. Sweeten *trítē* down to *mésē-trítē* 7:6; *paramésē*-on 16:15 follows.
5. Sweeten *parypátē* by taking *parypátē-trítē* 3:2; *hyperypátē-parypátē* 7:6 follows.

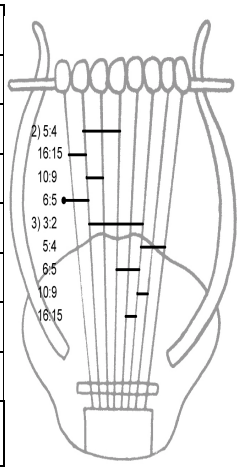
* Differs only 9 cents from resonant 7:6. This is virtually the same as Archytas, and so a mathematical fiction.

Chromatic: Figure 5 above, with Audio Example 12.

Diatonic: Audio Example 17.

hypátē 16:15 *parypátē* 10:9 *likhanós* 9:8 *mésē* 9:8
paramésē 16:15 *trítē* 10:9 *paranḗtē* 9:8 *nḗtē*

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.937	0.844	**3:4**	**2:3**	0.625	0.563	**1:2**
ph	1.067	1	**9:10**	**4:5**	0.711	**2:3**	0.600	0.533
l	1.185	**10:9**	1	**8:9**	0.79*	0.741	**2:3**	0.593
m	**4:3**	**5:4**	**9:8**	1	**8:9**	**5:6**	**3:4**	**2:3**
pm	**3:2**	1.406	1.265*	**9:8**	1	0.937	0.844	**3:4**
t	1.600	**3:2**	1.350	**6:5**	1.067	1	**9:10**	**4:5**
pn	1.778	1.666	**3:2**	**4:3**	1.185	**10:9**	1	**8:9**
n	**2:1**	1.875	1.688	**3:2**	**4:3**	**5:4**	**9:8**	1



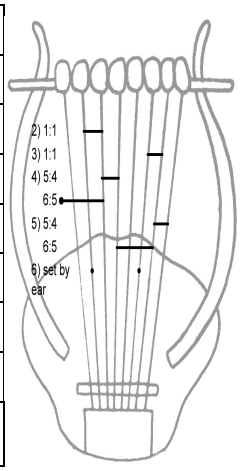
1. Tune diatonic.
2. Sweeten up *parypátē* to *parypátē-mésē* 5:4; *hypátē-parypátē* 16:15 *parypátē-likhanós* 10:9, *hyperypátē-parypátē* 6:5 follow.
3. Sweeten up *trítē* by taking *parypátē-trítē* 3:2 or *trítē-nḗtē* 5:4; *mésē-trítē* 6:5, *trítē-paranḗtē* 10:9, *paramésē-trítē* 16:15 follow.

Ptolemy

Enharmonic: Audio Example 18.

hypátē 46:45 *parypátē* 24:23 *likhanós* 5:4 *mésē* 9:8
paramésē 46:45 *trítē* 24:23 *paranḗtē* 5:4 *nḗtē*

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.978	0.938	**3:4**	**2:3**	0.652	0.625	**1:2**
ph	1.022	1	0.959	0.767	0.681	**2:3**	0.639	0.511
l	1.066	1.043	1	**4:5**	0.711	0.695	**2:3**	0.533
m	**4:3**	1.304	**5:4**	1	**8:9**	0.870	**5:6**	**2:3**
pm	**3:2**	1.468	1.407	**9:8**	1	0.978	0.938	**3:4**
t	1.533	**3:2**	1.438	1.150	1.022	1	0.959	0.767
pn	1.599	1.565	**3:2**	**6:5**	1.066	1.043	1	**4:5**
n	**2:1**	1.957	1.876	**3:2**	**4:3**	1.304	**5:4**	1

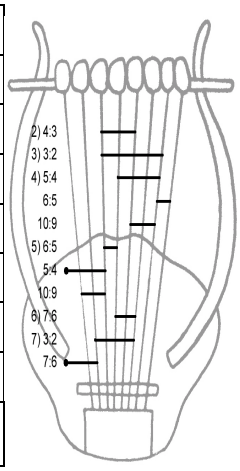


1. Tune basic diatonic.
2. Tune *parypátē-likhanós* 1:1.
3. Tune *trítē-paranḗtē* 1:1.
4. Sweeten up *likhanós* to *likhanós-mésē* 5:4, *hyperypátē-likhanós* 6:5, *hypátē-likhanós* 16:15 follow.
5. Sweeten up *paranḗtē* to *paranḗtē-nḗtē* 5:4; *mésē-paranḗtē* 6:5, *paramésē-paranḗtē* 16:15 follows.
6. Set *parypátē* and *trítē* by ear.

Soft Chromatic: Audio Example 19.

hypátē	28:27	*parypátē*	15:14	*likhanós*	6:5	*mésē*	9:8
paramésē	28:27	*trítē*	15:14	*paranḗtē*	6:5	*nḗtē*	

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.964	0.900	**3:4**	**2:3**	0.643	0.600	**1:2**
ph	1.037	1	0.933	0.778	0.691	**2:3**	0.622	0.519
l	**10:9**	1.072	1	**5:6**	0.741	0.715	**2:3**	0.556
m	**4:3**	1.286	**6:5**	1	**8:9**	**6:7**	**4:5**	**2:3**
pm	**3:2**	1.446	1.350	**9:8**	1	0.964	**9:10**	**3:4**
t	1.556	**3:2**	1.400	**7:6**	1.037	1	0.933	0.778
pn	1.667	1.608	**3:2**	**5:4**	**10:9**	1.072	1	**5:6**
n	**2:1**	1.929	1.799	**3:2**	**4:3**	1.286	**6:5**	1

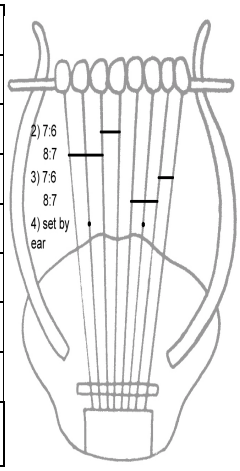


1. Tune diatonic.
2. Tune *likhanós-paramésē* 4:3.
3. Tune *likhanós-paranḗtē* 3:2.
4. Sweeten up *paranḗtē* to make *mésē-paranḗtē* 5:4; *paranḗtē-nḗtē* 6:5 and *paramésē-paranḗtē* 10:9 follow.
5. Sweeten *likhanós* by taking *likhanós-mésē* 6:5 (or *likhanós-paranḗtē* 3:2); *hyperypátē-likhanós.* 5:4, *hypátē-likhanós* 10:9 follow.
6. Sweeten down *trítē* to 7:6 w mésē; *trítē-paranḗtē* 15:14, *paramésē-trítē* 28:27 follow.
7. Sweeten *parypátē* by taking 3:2 with *trítē*; *hyperypátē-parypátē* 7:6, *hypátē-parypátē* 28:27, *parypátē-likhanós* 15:14 follow.

Tense Chromatic: Audio Example 20.

hypátē	22:21	*parypátē*	12:11	*likhanós*	7:6	*mésē*	9:8
paramésē	22:21	*trítē*	12:11	*paranḗtē*	7:6	*nḗtē*	

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.954	**7:8**	**3:4**	**2:3**	0.636	0.583	**1:2**
ph	1.048	1	**11:12**	0.786	0.699	**2:3**	0.611	0.524
l	**8:7**	**12:11**	1	**6:7**	0.762	0.727	**2:3**	0.571
m	**4:3**	1.272	**7:6**	1	**8:9**	0.848	0.778	**2:3**
pm	**3:2**	1.432	1.313	**9:8**	1	0.954	**7:8**	**3:4**
t	1.572	**3:2**	1.376	1.179	1.048	1	**11:12**	0.786
pn	1.714	1.636	**3:2**	1.286	**8:7**	**12:11**	1	**6:7**
n	**2:1**	1.909	1.750	**3:2**	**4:3**	1.272	**7:6**	1

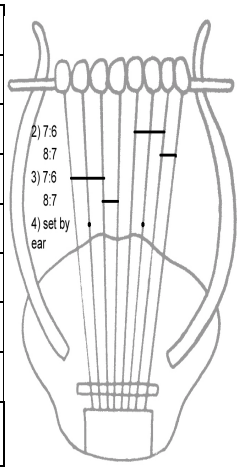


1. Tune diatonic.
2. Sweeten *likhanós* down to *likhanós-mésē* 7:6; *hypátē-likhanós* 8:7 follows
3. Sweeten *paranḗtē* down to *paranḗtē-nḗtē* 7:6; *paramésē-paranḗtē* 8:7 follows
4. Set *parypátē* and *trítē* by ear.

Soft Diatonic: Audio Example 21.

hypátē 21:20 *parypátē* 10:9 *likhanós* 8:7 *mésē* 9:8
paramésē 21:20 *trítē* 10:9 *paranḗtē* 8:7 *nḗtē*

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.953	**6:7**	**3:4**	**2:3**	0.635	0.571	**1:2**
ph	1.048	1	**9:10**	0.787	0.700	**2:3**	0.600	0.525
l	**7:6**	**10:9**	1	**7:8**	0.778	0.741	**2:3**	0.583
m	**4:3**	1.270	**8:7**	1	**8:9**	0.847	0.762	**2:3**
pm	**3:2**	1.429	1.286	**9:8**	1	0.953	**6:7**	**3:4**
t	1.575	**3:2**	1.350	1.181	1.050	1	**9:10**	0.787
pn	1.750	1.667	**3:2**	1.313	**7:6**	**10:9**	1	**7:8**
n	**2:1**	1.905	1.714	**3:2**	**4:3**	1.270	**8:7**	1



1. Tune diatonic.

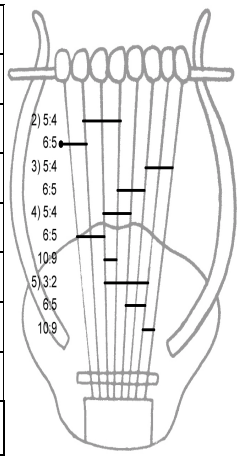
2. Sweeten *paranḗtē* down to *paramésē-paranḗtē* 7:6; *paranḗtē-nḗtē* 8:7 follows from division of *paramésē-nḗtē* 4:3.
3. Sweeten *likhanós* down to *hypátē-likhanós* 7:6; *likhanós-mésē* 8:7 follows
4. Set *parypátē* and *trítē* by ear (7:6 divided into 10:9 and 21:20, 10:9 is a mathematical fiction).

Tonic Diatonic: same as Archytas' Diatonic: Figure 4 above, with Audio Example 10.

Tense Diatonic: Audio Example 22.

hypátē	16:15	*parypátē*	9:8	*likhanós*	10:9	*mésē* 9:8
paramésē	16:15	*trítē*	9:8	*paranḗtē*	10:9	*nḗtē*

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.938	**5:6**	**3:4**	**2:3**	0.625	0.556	**1:2**
ph	1.066	1	**8:9**	**4:5**	0.711	**2:3**	0.593	0.533
l	**6:5**	**9:8**	1	**9:10**	**4:5**	**3:4**	**2:3**	0.600
m	**4:3**	**5:4**	**10:9**	1	**8:9**	**5:6**	0.741	**2:3**
pm	**3:2**	1.407	**5:4**	**9:8**	1	0.938	**5:6**	**3:4**
t	1.599	**3:2**	**4:3**	**6:5**	1.066	1	**8:9**	**4:5**
pn	1.799	1.688	**3:2**	1.350	**6:5**	**9:8**	1	**9:10**
n	**2:1**	1.876	1.667	**3:2**	**4:3**	**5:4**	**10:9**	1



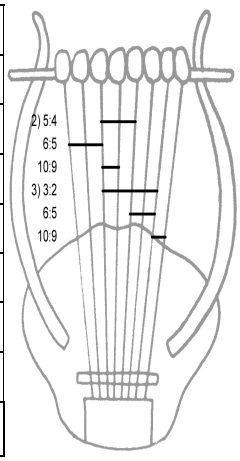
1. Tune diatonic.
2. Sweeten up *parypátē* to *parypátē-mésē* 5:4; *hyperypátē-parypátē* 6:5 and *hypátē-parypátē* 16:15 follow.
3. Sweeten up *trítē* to *trítē-nḗtē* 5:4; *mésē-trítē* 6:5 follows.
4. Sweeten up *likhanós* to *likhanós-paramésē* 5:4; *likhanós-hypátē* 6:5, *likhanós-mésē* 10:9 follow.
5. Sweeten up *paranḗtē* by taking *likhanós-paranḗtē* 3:2; *paramésē-paranḗtē* 6:5, *paranḗtē-nḗtē* 10:9, and *paramésē-trítē* 16:15 follow.

Ditonic Diatonic: Figure 1 above, with Audio Example 4.

Even Diatonic: Audio Example 23.

hypátē	12:11	*parypátē*	11:10	*likhanós*	10:9	*mésē* 9:8
paramésē	12:11	*trítē*	11:10	*paranḗtē*	10:9	*nḗtē*

	h	*ph*	*l*	*m*	*pm*	*t*	*pn*	*n*
h	1	0.917	**5:6**	**3:4**	**2:3**	0.611	0.556	**1:2**
ph	**12:11**	1	**10:11**	0.818	0.727	**2:3**	0.606	0.545
l	**6:5**	**11:10**	1	**9:10**	**4:5**	0.733	**2:3**	0.600
m	**4:3**	1.223	**10:9**	1	**8:9**	0.815	0.741	**2:3**
pm	**3:2**	1.376	**5:4**	**9:8**	1	0.917	**5:6**	**3:4**
t	1.636	**3:2**	1.364	1.227	**12:11**	1	**10:11**	0.818
pn	1.799	1.650	**3:2**	1.350	**6:5**	**11:10**	1	**9:10**
n	**2:1**	1.834	1.667	**3:2**	**4:3**	1.223	**10:9**	1



1. Tune diatonic.
2. Sweeten up *likhanós* to make *likhanós-paramésē* 5:4; *hypátē-likhanós* 6:5, *likhanós-mésē* 10:9 follow.
3. Sweeten up *paranḗtē* by taking *likhanós-paranḗtē* 3:2; *paramésē-paranḗtē* 6:5, *paranḗtē-nḗtē* 10:9.

Bibliography

Barker 1978a — A. Barker, Music and Perception: A Study in Aristoxenus. Journal of Hellenic Studies 98, 9–16.

Barker 1978b — A. Barker, Hoi kaloumenoi harmonikoi: The predecessors of Aristoxenus. Proceedings of the Cambridge Philological Society 24, 1–21.

Barker 1982 — A. Barker, The innovations of Lysander the kitharist. Classical Quarterly n.s. 32, 266–269.

Barker 1984 — A. Barker, Greek Musical Writings I. Cambridge.

Barker 1989 — A. Barker, Greek Musical Writings II. Cambridge.

Brancacci 1988 — A. Brancacci, Alcidamante e PHibeh 13 ‘De musica’: Musica della retorica e retorica della musica. In: A. Brancacci et al., Aristoxenica, Menandrea, Fragmenta Philosophica. Accademia Toscana, Studi 91, 61–84.

Burkert 1972 — W. Burkert, Lore and Science in Ancient Pythagoreanism. Cambridge Mass.

DAGM — E. Pöhlmann / M.L. West, Documents of Ancient Greek Music. Oxford 2001.

Franklin 2002a — J.C. Franklin, Diatonic Music in Greece: A reassessment of its antiquity. Mnemosyne 56.1, 669–702.

Franklin 2002b	J.C. Franklin, Musical syncretism and the Greek Orientalizing Period. In E. Hickmann / R. Eichmann (edd.), Studien zur Musikarchäologie 3, Orient-Archäologie 10, 441–451.
Franklin 2002c	J.C. Franklin, Terpander: The Invention of Music in the Orientalizing Period. Ph.D. Dissertation, University College London.
Franklin 2003	J.C. Franklin, The language of Musical technique in Greek epic diction. Gaia 7, 295–307.
Gurney 1968	O.R. Gurney, An Old Babylonian treatise on the tuning of the harp. Iraq 30, 229–233.
Gurney 1994	O.R. Gurney, Babylonian music again. Iraq 56, 101–106.
Hagel 2000	S. Hagel, Modulation in altgriechischer Musik: Antike Melodien im Licht antiker Musiktheorie. Frankfurt am Main.
Hagel 2004	S. Hagel, Calculating auloi: the Louvre aulos scale. Forthcoming in: E. Hickmann / R. Eichmann (edd.), Studien zur Musikarchäologie 4, Orient-Archäologie 15, !!.
Helmholtz 1895	H.L.F. Helmholtz, The Sensations of Tone. 3rd ed., London / New York.
Howard 1893	A.A. Howard, The aulos or tibia. Harvard Studies in Classical Philology 4 , 1–63.
Jan 1895	K. von Jan, Musici scriptores Graeci: Aristoteles, Euclides, Nicomachus, Bacchius, Gaudentius, Alypius. Leipzig.
Laloy 1904	L. Laloy, Aristoxène de Tarente et la musique de l'antiquité. Paris, 1904.
Maas/Snyder 1989	M. Maas / J. Snyder, Stringed Instruments of Ancient Greece. New Haven / London.
Monro 1894	D.B. Monro, The Modes of Ancient Greek Music. Oxford.
Roberts 1980	H.H. Roberts, The technique of playing ancient Greek instruments of the lyre type. In: T.C. Mitchell (ed.), Music and Civilization. British Museum Yearbook 4, London, 43–76.
Rocconi 2004	E. Rocconi, Colours in music: Metaphoric musical language in Greek antiquity. Forthcoming in: E. Hickmann / R. Eichmann (edd.), Studien zur Musikarchäologie 4, Orient-Archäologie 15, !!.
Sachs 1924	C. Sachs, Die griechische Instrumentalnotenschrift. Zeitschrift für Musikwissenschaft 1923–4, 289–301.
Scheltema 1932	H.J. Scheltema, De antiphonia. Mnemosyne 60, 239–53.
Thurn 1998	N. Thurn, Die Siebensaitige Lyra. Mnemosyne 51, 411–434.
Wallace 1995	R.W. Wallace, Music theorists in fourth-century Athens. In: B. Gentili / F. Perusino (edd.), Mousike. Metrica ritmica e musica greca. Pisa/Rome, 17–39.
Wallace 2003	R.W. Wallace, An early fifth-century Athenian revolution in aulos music, Harvard Studies in Classical Philology 101, 73–92.

Wehrli 1967	F. Wehrli, Aristoxenos (Die Schule des Aristoteles, 2). 2nd ed., Basle.
West 1992	M.L. West, Ancient Greek Music. Oxford.
West 1992b	M.L. West, Analecta musica. Zeitschrift für Papyrologie und Epigraphik 92, 1–54.
Wilson 1999	P. Wilson, The *aulos* in Athens. In: S. Goldhill / R. Osborne (edd.), Performance culture and Athenian democracy. Cambridge, 58–95.
Winnington-Ingram 1932	Aristoxenus and the intervals of Greek music. Classical Quarterly 26 , 195–208.
Winnington-Ingram 1936	Mode in Ancient Greek Music. Cambridge.
Winnington-Ingram 1956	R.P. Winnington-Ingram, The pentatonic tuning of the Greek lyre: A theory examined. Classical Quarterly 6, 169–186.
Wulstan 1968	D. Wulstan, The tuning of the Babylonian harp. Iraq 30, 215–228.